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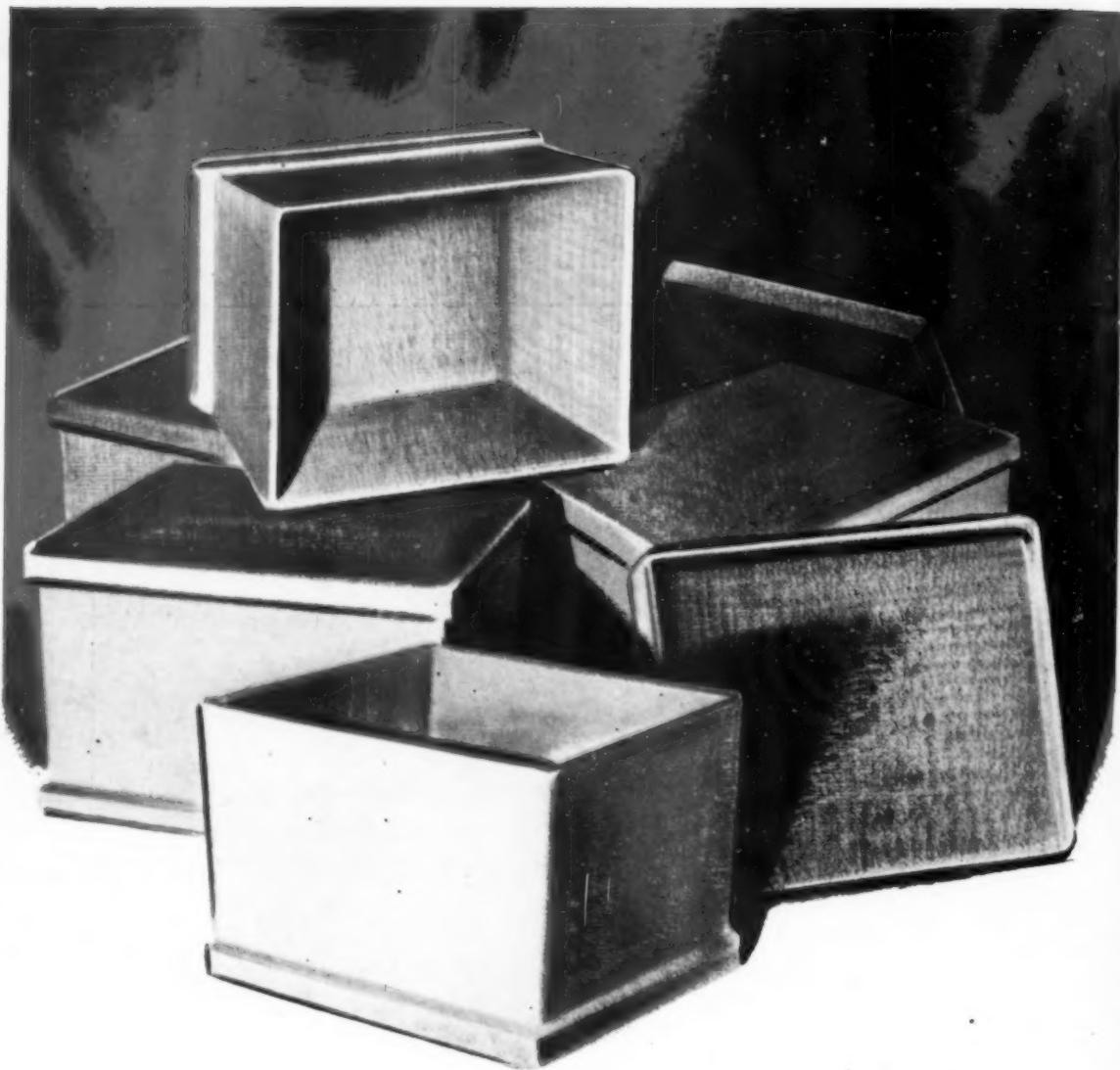
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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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W E L L M A N



Britain's Steel . . .

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

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The Electron in Theory and Practice

THE recognition of the electron fifty years ago as the ultimate particle of electricity and a constituent of all atoms was a new conception which had repercussions far beyond the limited range of phenomena which prompted it in the first instance. At once it gave a completely new orientation to the atomic theory of matter which till then had been based almost entirely on chemical considerations. In experimental physics it converted a field which was becoming dry and somewhat sterile into one of the richest and most fertile regions of scientific inquiry. Some interesting aspects of this discovery were discussed by Sir Edward Appleton in the Second Dunn Memorial Lecture, which he delivered in Newcastle, recently, to the Society of the Chemical Industry. They show the tremendous influence the results of experiments can have on mankind.

In the realm of practical applications the discovery of the electron has had an influence equally revolutionary. The methods by which intelligence is nowadays communicated over a distance almost instantaneously without wires—by broadcasting, television and radio generally—are all pursued with electronic devices. Radar is essentially an electronic subject; while electronic control devices in industry are already contributing to the efficiency of manufacturing processes and doing much to reduce monotonous routine work.

The electron has even invaded the territory of the mathematician, for there have already been designed calculating machines, employing thousands of thermionic tubes, by which the most complicated mathematical expressions can be evaluated and equations solved. If such matters were tackled by unaided human beings the effort would be terribly laborious.

It would be rash to attempt to guess what the future holds in store but Sir Edward thought it could be justly said that we were now only entering upon what may be called the electronic age. It has been estimated that in America already, nearly one-tenth of all the electrical energy now generated passes through electronic devices.

Sir Edward traced the manner in which the conception of the electron had provided satisfactory explanations of many phenomena in physics and chemistry. In recent years the remarkable discovery had been made that electrons can be created and annihilated. This is accounted for by Einstein's Special Theory of Relativity. Actually it is found that the annihilation of a packet of light energy, a photon, gives birth to both a brother and sister—a negatively charged electron and a positively charged particle of the same mass.

Dealing with the application of electrons he said that theoretically, it should be possible to amplify the current corresponding to the passage of one thousand electrons per second through a resistance, that is a current of about one-thousandth of one-millionth of a millionth of an ampere. Equipment had been developed by which

electrical charges produced by a variation of temperature of one or two degrees in a steel making furnace could be amplified by electronic means so as to control the fuel supply to the furnace and maintain its temperature constant to within about one-tenth of 1% at 1,600° C. In the textile industry another application was an electronic instrument which enabled the cotton yarn and cloth to be maintained at the right moisture content so that processing could be carried out consistently and accurately without attention from the operator.

Sir Edward Appleton referred to the electronic valves, called magnetrons, used in radar, which reached a peak output of 1,000 kilowatts in the generation of radio waves of 10 centimetres in length. He went on to describe how infra-red sensitive cells had enabled objects to be seen in the dark when hot or illuminated by invisible infra-red radiation. He explained how electrons had been pressed into the service of illumination so that "daylight" fluorescent lamps had been produced giving a much higher efficiency than is possible with filament lamps. It is estimated that if all the artificial lighting in this country were carried out with this type of lamp a saving of two million tons of coal a year would be effected and the generating capacity of two power stations of the size of Battersea could be redeployed.

He concluded by describing electron microscopes in which electron beams were used instead of light for illuminating the object to be examined, and the lenses, instead of being of glass, consisted of magnetic or electrostatic fields. With these instruments a useful magnification of 50,000 diameters was being achieved and it might well be possible, he said, to obtain magnifications of one hundred or even two hundred thousand with them. Objects which themselves are so small as to be transparent such as many bacteria, viruses, smoke and other particles, are particularly suitable for examination by electron microscopes.

In conjunction with the Ministry of Supply and a number of Research Associations, the Department of Scientific and Industrial Research have recently been paying a good deal of attention to possible industrial applications of electronics. An Advisory Panel under the chairmanship of Sir Charles Darwin, Director of the National Physical Laboratory, has been formed, which aims at bringing together the research worker, the supplier and the user, and, in addition, groups have been formed at the Telecommunications Research Establishment of the Ministry of Supply, and at the National Physical Laboratory to examine industrial problems at first hand with a view to suggesting how electronic equipment could be employed in their solution. These activities should help to step up the volume of production.

Thus, the results of a series of experiments carried out quietly just over half a century ago, in a Cambridge Physics Laboratory have given not only new impetus to many branches of science, but have profoundly modified the way in which we go about our lives and work.

Plea for a Broader Education

THE Joint Committee on Metallurgical Education was formed by the Councils of The Iron and Steel Institute, The Institution of Mining and Metallurgy, The Institute of British Foundrymen, The Institute of Metals and The Institution of Metallurgists in order to advise and represent them on matters connected with education. Apart from its industrial members, the Committee includes Professors of Metallurgy at British Universities, Principals of Technical Colleges and Education Officers in industry.

Recently the Committee has considered the standard of general education desirable in those entering University Schools of Metallurgy in the United Kingdom. This subject is clearly of great importance and the recent publication of the White Paper on Examinations in Secondary Schools* makes its consideration at the present time very opportune.

The Committee's views are set out in a pamphlet entitled "Recommendations on Qualifications for Entrance to University Schools of Metallurgy, copies of which may be obtained on application to the Secretary of the Committee, 4, Grosvenor Gardens, London, S.W.1.

The central theme of the recommendations is a strong plea for a broader education, immediately prior to, or in the early stages of University training. The Committee believes, and the belief is confirmed by the industrial members who are employers of graduates in other sciences, that its opinions are equally applicable to graduates in any of the pure and applied sciences. Boys and girls in their final years at school are all too often subjected to a degree of specialisation which, the Committee believes, is responsible for the production of University Students who are narrow in outlook and lacking in intellectual balance.

Whether a student enters the University at Matriculation standard and takes an extra year in proceeding to an honours degree, or whether as is more usual he stays on at school for a further period in order to take his High School Certificate or Intermediate Examination, it is felt that the remedy lies in the hands of the Universities. Generally speaking the matriculation examination is on a broad basis, but if a completely balanced education is to be secured, further steps should be taken by the Universities to ensure that up to Intermediate standard the student should retain a close contact with subjects other than science, and should be required to provide evidence of competence in such other subjects. In the case of students entering at matriculation level, this is purely a domestic matter for the Universities, but for those entering at Intermediate level the committee considers that the Universities can act through the entrance examination, by demanding that candidates must pass in some subjects chosen from a wide range of non-scientific options.

University entrance examinations for those intending to study metallurgy should recognise the two levels of entrance, and papers corresponding to each level should be set in each of the following groups: (1) A paper based on written English, designed to test the student's ability to express himself in writing; (2) A paper in mathematics of a standard suited to ensure that the student is capable of benefiting from his University course; (3) A paper or papers on chemistry, physics or general science, and (4) at least one paper selected from a number of alternative humanistic subjects other than English. Candidates

wishing to enter at intermediate level could profitably take the high papers in all subjects. Success at the higher standard would be compulsory in groups (1), (2) and (3), even though the lower standard were accepted in the others.

Even if such a scheme resulted in a somewhat lower standard of the science subjects, it would be a small price to pay for a more balanced culture in metallurgical graduates, and it is doubtful whether, on completion of the University course, there would be any appreciable difference in the standards attained in metallurgy.

Under the present system of University entrance scholarship examinations, the type of paper and competitive nature of the test have probably been the reason for the early specialisation which is so much deplored by the Committee. If the practice of holding separate scholarship examinations is to continue, the papers should be based on a broad syllabus, as is recommended for the entrance examinations.

Finally the Committee, whilst doubting the wisdom of selecting University entrants by personal interview instead of by written test, has no such doubts on the use of personal interviews in selecting men after graduation.

International Institute of Welding

WELDING has recently achieved organisation on an international scale by the formation of the International Institute of Welding, at a meeting in Brussels, attended by the representatives of 14 countries.

A special responsibility has fallen to the British welding community through the election, as the first Secretary-General of the international body, of Mr. G. Parsloe, the secretary of the British Institute.

The primary business of the meeting was to establish the Institute and to set up a number of special commissions on various technical subjects. In addition, two sessions were devoted to technical papers, each of which reviewed the existing knowledge in a given field of study and formulated suggestions for further research.

It is intended that an annual meeting of this character shall be organised in future, and the Governing Council have accepted an invitation from the Netherlands to meet there in 1949. They have also accepted an invitation from the British delegation to hold the first World Welding Congress in Great Britain.

British Welding Research Association

At the Annual General Meeting of the British Welding Research Association, held on Thursday, 8th July, the following members of Council who had retired by rotation were re-elected: Mr. A. J. Boyd, Mr. H. W. Clarke, Sir Andrew McCance, F.R.S., Dr. J. H. Paterson, Mr. C. M. Spielman, M.C.

Commander Sir Robert Micklem, C.B.E., R.N. and Mr. V. E. Greenwood, having retired from Council were not able to allow their names to go forward for re-election and a hearty vote of thanks was voted at the meeting in recognition of their services to the Council and the Association.

The following who have not previously served on the Council of the Association were elected members:

Mr. L. P. Lord, Austin Motor Co., Ltd.; Mr. F. C. Mannox, Murex Welding Processes, Ltd.; Mr. J. A. Oriel, C.B.E., Shell Refining and Marketing Co., Ltd.; Vice-Admiral Sir Charles Simeon, K.B.E., C.B., Vickers-Armstrong Ltd., Mr. J. H. N. Thompson, John Thompson (Wolverhampton), Ltd.

* Ministry of Education, Report of the Secondary School Examinations Council, 1947 London, 1947. H.M. Stationery Office.

The Thermal Etching of Metals

By R. Shuttleworth, B.Sc.

H. H. Wills Physical Laboratory, University of Bristol.

When a polished metal specimen is maintained at a high temperature grooves develop where the crystal boundaries intersect the surface, and in some atmospheres striations form on the crystals. Observations of these phenomena for iron and steel, copper, tungsten and tantalum, and silver are reviewed. The various theories advanced to explain the formation of boundary grooves and striations are critically discussed, and it is suggested that they are formed mainly by the surface migration of metallic ions, which transfers metal until an equilibrium surface of minimum energy is attained.

METALS, as normally encountered, are polycrystalline, being formed from an aggregate of differently orientated crystals. In each crystal the atoms are arranged on a regular lattice, and joining the crystals are transition regions of relative disorder probably no more than a few atoms thick. This structure is usually displayed by polishing the surface of a specimen and etching with a chemical reagent. The differences in orientation of the crystals are shown by the shapes of the etch pits on their surfaces; grooves sometimes develop where the crystal boundaries intersect the surface.¹

Alternatively the structure may be displayed by thermal etching. The polished specimen is heated in a vacuum or in an atmosphere with which it does not form a stable compound. In inert atmospheres most metals develop grooves at the crystal boundaries, Fig. 1a. Some metals, when heated in a specific atmosphere, develop striations which cover the crystal surfaces, and their form and direction depend upon the crystal orientation, Fig. 1b. The phenomena of thermal etching have been known for forty years and recently Shuttleworth, King and Chalmers^{2,3} have studied in detail the thermal etching of silver.

These authors consider that the essential mechanism by which thermal etching occurs is the transfer of atoms from one part of the surface to another most probably by surface migration, and that the final surface is an equilibrium structure with minimum free energy. They distinguish thermal etching from chemical attack where atoms are continuously dissolved, and there is no reason to suppose that the final surface is one of minimum free energy; from heat tinting in which the surface is left covered with an oxide film; and from thermal fatigue.

The appearance of a specimen after thermal fatigue, in which it is alternately heated and cooled, is similar to that after thermal etching, which occurs at constant temperature, and the two phenomena have been confused. Thermal fatigue has been described by Boas and Honeycombe,^{4,5} who found the crystal boundaries were delineated, and striations developed on the crystal surfaces, when polished specimens of the non-cubic metals, tin, zinc, and cadmium were alternately heated and cooled. They attributed these effects to the anisotropy in the thermal expansion of the non-cubic crystals; when a randomly orientated aggregate is heated or cooled

this anisotropy is sufficient to cause plastic deformation. The striations are the resulting slip lines, and the boundary delineation the differences in level between adjacent crystals. The correctness of this explanation is clear because the same phenomena can be produced by cooling the specimens in liquid air, as well as by heating them above room temperature. Carpenter and Elam⁶ had previously used these phenomena to study grain growth in tin alloys. However, the boundary grooves and striations, which occur on thermally etching the cubic metals iron, copper, silver, tungsten, and tantalum, cannot be due to this cause, and it is probable that thermal etching is a property common to all metals, cubic and non-cubic, alike.

A phenomenon whose nature is obscure and is perhaps related to thermal etching, is the roughening of metal surfaces which occurs when they act as catalysts in gas reactions. Beilby⁷ found that when copper, iron, nickel, platinum and gold catalyse the decomposition of gaseous ammonia at 800° C., the surface area increased to such an extent that the metal became spongy and lost its mechanical strength. Ransley⁸ found that silver was roughened when hydrogen and oxygen react on its surface. Gwathmey and Benton⁹ heated to 360° C. a spherical single crystal of copper in a mixture of hydrogen and oxygen; they found that the surface atoms rearranged themselves to produce definite rough and smooth regions, and simultaneously the rate of oxidation of the hydrogen increased. Similar results for steel heated in burnt town gas, are reviewed by Jenkins.¹⁰ If the CO, CO₂, H₂, and H₂O components of the gas are in equilibrium only normal crystal boundary thermal etching occurs. If, however, these components are not in equilibrium with each other at the temperature of the experiment their reactions are catalysed on the steel surface and it becomes rough.

A further effect, whose connection with thermal etching has not been investigated, is the surface structure of cast metals. Striations on such surfaces were first noticed by Ewing and Rosenhain;¹¹ Graf¹² gives numerous examples and attributes them to a micro-mosaic structure in the metal crystals.

Iron and Steel

At the beginning of this century, thermal etching was used by a number of workers to elucidate the phase

¹ Lacombe and Beaujard, *J. Inst. Metals*, 1947, **74**, 1.
² Shuttleworth, King and Chalmers, *Nature*, 1945, **158**, 482.
³ Shuttleworth, King and Chalmers, *Proc. Roy. Soc. A*, 1948, (In course of publication).
⁴ Boas and Honeycombe, *Proc. Roy. Soc. A*, 1946, **186**, 57.
⁵ Boas and Honeycombe, *Proc. Roy. Soc. A*, 1947, **188**, 427.

⁶ Carpenter and Elam, *J. Inst. Metals*, 1920, **24**, 83.
⁷ Beilby, "Aggregation and Flow in Solids (Macmillan, 1921), p. 41.
⁸ Ransley, *J. Inst. Metals*, 1940, **71**, 625.
⁹ Gwathmey and Benton, *J. Chem. Physics*, 1940, **8**, 569.
¹⁰ Jenkins, "Controlled Atmospheres for the Heat Treatment of Metals" (Chapman and Hall, 1946), p. 222.
¹¹ Ewing and Rosenhain, *Phil. Trans. Roy. Soc. A*, 1900, **193**, 355.
¹² Graf, *Z. Electrochem.*, 1942, **46**, 181.

changes which occur in iron and steel at high temperatures. Rosenhain and Humfrey¹³ were the first to observe that there appear on iron heated in a vacuum two networks of boundary grooves intersecting at random. Kroll¹⁴ obtained a confused network of grooves when he heated iron, in hydrogen, above A_3 point and erroneously interpreted them as the boundary networks corresponding to α , β and γ iron. In 1912 Humfrey¹⁵ heated steel in a vacuum and found two sets of boundary grooves. He correctly interpreted them as the boundaries of the austenite and ferrite crystals, the allotropic forms of iron above and below the A_3 point. He also noted that straight twin boundaries occur in the austenite crystals, and that there were indications of veining or internal subdivision of the ferrite grains.

Rawdon and Scott¹⁶ confirmed Humfrey's hypothesis by showing that when electrolytic iron is heated below the A_3 point for 30 minutes in a vacuum only one set of boundary grooves, corresponding to ferrite, appear. After heating mild steel in vacuum below the A_1 eutectoid temperature, they found that the pearlite islands could be distinguished. At temperatures above the A_1 point surface decarburisation occurred which they attributed to the evaporation of carbon from the austenite; thermal etching showed the structure of the metal as it was before and after this decarburisation. Similar results were obtained by Hemingway and Ensminger¹⁷ who attributed surface decarburisation, in vacuum, to volatilisation of iron followed by recondensation. They found that at these temperatures carbon is oxidised to carbon monoxide by the oxide inclusions or by any surface layer of oxide; the author considers this a more probable mechanism for decarburisation.

In 1928 Rawdon and Berglund¹⁸ carried out a detailed investigation into the nature of the veining of ferrite, first noticed on thermally etched specimens by Humfrey¹⁵. They proved that both the boundary and veining marks, produced by heating iron in hydrogen, were grooves and not steps. They found that the veins were characteristic of each ferrite crystal and were not transmitted across the boundary to the next crystal. Their most interesting discovery was that electrolytic iron developed striations when heated to 750°–800° C for 100 hours in dry commercial hydrogen. These striations were almost identical with those formed on silver heated in air³. Photomicrographs show that the striations on some crystals change their direction by a constant angle where they intersect what appear to be twin boundaries, and this suggests a form of twinning in ferrite different from Neumann bands.

Sauerwald and his co-authors^{19,20} found a similar veining on electrolytic iron etched in vacuum. They state that only in the case of eutectoid steels is it possible to preserve after slow cooling, the structure developed at a high temperature by thermal etching; other steels must be quenched. Using thermal etching to identify the austenite crystal boundaries of carbon steels they showed that the martensite, formed on quenching, changes orientation at these boundaries.

When a carbon steel is quenched from the austenitic region the alternative reactions of pearlite and martensite

formation are possible. Pearlite formation is nucleated at the austenite crystal boundaries, martensite formation occurs inside the austenite crystals. Therefore, the hardenability (the depth to which the martensitic structure extends after quenching) will be greater if the steel has a large austenitic grain size. It is often useful to estimate this grain size and numerous methods have been devised, but none were applicable to steels of all carbon contents until Day and Austin²¹ developed a technique using thermal etching.

In order to make a reliable estimate of grain size they found it necessary to heat the steel in an atmosphere which did not affect the composition of the surface layer. Nitrogen, hydrogen, or a mixture of the two were satisfactory, but it was essential to remove the last traces of oxygen.²² If this was not done any aluminium in the surface layer oxidised and austenite grain growth was inhibited, the surface structure then developed by thermal etching was not typical of that in the centre of the steel. The deoxidation and decarburisation of the surface layer by the hydrogen was important only at temperatures near the melting point.

To make easier the rapid assessment of austenitic grain size they suppressed veining and ferrite boundary grooves by quenching the specimen. It was heated in a vertical furnace closed at the bottom by a bath of mercury, and quenched by dropping into the mercury. After this quenching wrinkles formed on the surface; these they attributed to the formation of martensite, even in steels of very low carbon content.

They found that though twin boundaries were developed in the austenite grains they were much less pronounced than were the crystal boundaries. The boundary grooves of a 0.07% C steel formed after heating to 1,000° C. for only 10 minutes. At this temperature grain growth was rapid, but in specimens quenched after successive intervals the structure was not confused and grooves appeared only at the final positions of the boundaries.

Parker and Smoluchowski²³ observed that molten silver spread by capillary attraction in the boundary grooves of ferritic iron containing 6% manganese.

Copper

Rosenhain and Ewen²⁴ were the first to note that when a polished specimen of copper is heated in a vacuum at about 1,000° C. boundary grooves develop; this was confirmed by Sauerwald, Schultze and Jackwirth.¹⁹ Elam²⁵ found that when copper was heated to 900°–950° C. in a vacuum of 0.5 mm. striations developed on the surface of most crystals but only if the copper contained inclusions of cuprous oxide. If, however, a plug of oxygen-free copper, which does not striate, was inserted into oxygen-containing-copper, striations developed on both surfaces. This showed that the striations are due to the decomposition of the oxide and the diffusion of oxygen through the copper to the surface. Striations could also be made to appear on oxygen-free copper by first forming a cuprous oxide layer on the surface and then heating in a vacuum. The oxide layer disappeared and left the crystal surfaces bright but striated. Elam proved that the cuprous oxide disappeared by the process of evaporation in molecular

13 Rosenhain and Humfrey, *Proc. Roy. Soc. A.*, 1910, **83**, 200.

14 Kroll, *Carnegie Mem. Iron and Steel Inst.*, 1912, **4**, 8.

15 Humfrey, *Carnegie Mem. Iron and Steel Inst.*, 1912, **4**, 80.

16 Rawdon and Scott, *Trans. A.I.M.M.E.*, 1922, **67**, 414.

17 Hemingway and Ensminger, *Trans. A.I.M.M.E.*, 1922, **67**, 392.

18 Rawdon and Berglund, *Sci. Papers Bur. Stand.*, 1928, **22**, 649.

19 Sauerwald, Schultze and Jackwirth, *Z. Anorg. All. Chem.*, 1924, **140**, 384.

20 Sauerwald and Jackwirth, *Z. Anorg. All. Chem.*, 1924, **140**, 391.

21 Day and Austin, *Trans. A. Soc. Metals*, 1940, **28**, 354.

22 Miller and Day, *Trans. A. Soc. Metals*, 1942, **30**, 541.

23 Parker and Smoluchowski, *Trans. A. Soc. Metals*, 1945, **33**, 362.

24 Rosenhain and Ewen, *J. Inst. Metals*, 1912, **8**, 149.

25 Elam, *Trans. Faraday Soc.*, 1936, **32**, 1604.

form; for there was a net loss of weight when the copper was oxidised and then heated in a vacuum until the oxide disappeared. This loss could not be due to the decomposition of the oxide, for metallic copper is not appreciably volatile at these temperatures.

Elam also developed striations on large single crystals of copper; and found that the striations formed by repeated treatment of one face or of a series of parallel faces always had the same directions and the same spacings. By forming striations on two, or sometimes three, orthogonal faces of a single crystal she showed that the striations were not the trace of the intersection of a unique crystallographic plane with the faces of a crystal, but that the directions of the striations on separate faces were consistent with their being the intersection of $\{100\}$ and $\{110\}$ planes with that face.

Gwathmey and Benton^{26,27} examined the action of gases on the surface of a spherical single crystal of copper, which they had prepared unoxidised and strain free by electrolytic polishing followed by an anneal in hydrogen. They found that heating in a vacuum of 10^{-4} mm. or in hydrogen at atmospheric pressure, caused no change to the surface of the crystal. However, a sphere heated to $1,000^{\circ}\text{C}$. in air at a pressure of 0.3 mm. showed preferential oxidation, and circular striations appeared spreading out to 3–5 mm. diameter around the $\langle 110 \rangle$ and $\langle 111 \rangle$ poles of the crystal. The striations were caused by the development of $\{110\}$ and $\{111\}$ planes in these positions. When the sphere was heated to 580°C . in hydrogen the oxide film disappeared and the striations were diminished. From these experiments Gwathmey and Benton concluded that at temperatures well below the melting point of the copper, rearrangements of the surface atoms can occur to produce facets with simple crystallographic indices. They suggested that these facets are probably the active centres at which catalysis is concentrated.

Tungsten and Tantalum

Fonda²⁸ found that boundary grooves develop in tungsten filaments if they are heated to $2,677^{\circ}\text{C}$. in a vacuum or in an inert atmosphere. Johnson²⁹ examined the tungsten filaments from several hundred burned-out incandescent lamps, after they had been heated by alternating and by direct current in a vacuum, in nitrogen, in argon, and in a mixture of argon and nitrogen. He found that the surface structure could be unambiguously divided into four classes.

1. *A.C. in vacuum.* At the centre portion of the filament only boundary grooves developed. At the ends of the filament there was a thermal gradient and here a sawtooth step structure developed; this was similarly oriented on all portions of a single crystal, the saw-teeth always pointing towards the cool end of the wire.

2. *A.C. in inert gas.* A regular structure of smooth crystal faces, with linear dimensions of the order of magnitude of the wire diameter appeared. The structure increased in complexity with increasing wire size. Goniometric study suggested that, if this process were to proceed to completion only the $\{100\}$ crystal faces would remain. Where a thermal gradient existed in the filament, the step structure was superimposed upon the crystal faces.

3. *D.C. in vacuum.* This structure appeared identical

with the step structure produced by a thermal gradient and A.C. heating. In this case the saw teeth pointed towards the negative end of the wire.

4. *D.C. in inert gas.* On these wires the gas structure found on A.C. filaments and the D.C. structure found on vacuum filaments occurred concurrently.

Johnson found that a variation in the frequency of the A.C. between 0.01 c/s and 25 mc/s made no difference to the A.C. structure, and he concluded that heating by A.C. was equivalent to heating without the passage of current. He supposed the D.C. step structure arose from the surface migration of positively charged tungsten ions and that this migration was influenced by both the D.C. potential field, and the crystal directions; migration being easier in some directions than in others. This hypothesis was further strengthened when he found that thorium atoms, deposited on a tungsten filament, showed preferential surface migration towards the negative terminal.

On the same hypothesis of surface ionic migration he explained the structure caused by a thermal gradient, in this case the ions showed a preferential migration towards the cooler regions. The identity of the thermal gradient and D.C. structures proved that the crystallographic directions favourable to surface migration are the same in thermal and potential gradients.

Johnson pointed out that the crystal facets which occurred on heating the filament by A.C. in an inert gas could not have been formed by evaporation alone. In order to form the facets by evaporation a 20% loss of weight would have been necessary, and this was not found. The facets must have been produced by the transfer of atoms; and since they occur after heating in argon but not in vacuum, he suggested that the atoms evaporated but were then reflected back on to the surface after collision with the gas atoms.

Johnson found that grooves left by the diamond die on the filament surface disappear after heating at the normal temperature for about 50 hours; but suggests that long before they suffer any large scale changes, they adjust themselves to some standard condition by surface migration or by preferential evaporation.

Mrowca³⁰ obtained very similar results with tantalum ribbon, he explained them in the same way as did Johnson.

Silver

It is well known that although silver does not oxidise when heated in air its surface takes on a matt appearance. Rosenhain and Ewen,³¹ in their classic paper on the amorphous theory of the crystal boundary, were the first to investigate the surface changes which occur when silver is heated in air and in a vacuum. They found that the matt appearance was due to the formation of striations on the crystal surfaces. Striations and boundary grooves appeared when the silver was heated in air, but only boundary grooves in a vacuum. Leroux and Raub³¹ found striations on silver heated in oxygen, but not on that heated in hydrogen.

For their work on thermal etching Shuttleworth, King and Chalmers^{2,3} selected silver because even in oxygen at atmospheric pressure solid silver oxide, Ag_2O , is unstable and decomposes at temperatures greater than 200°C ., whilst below this temperature the

²⁶ Gwathmey and Benton, *J. Chem. Phys.*, 1940, **8**, 431.

²⁷ Gwathmey and Benton, *J. Phys. Chem.*, 1942, **46**, 969.

²⁸ Fonda, *Phys. Rev.*, 1923, **21**, 342.

²⁹ Johnson, *Phys. Rev.*, 1938, **54**, 459.

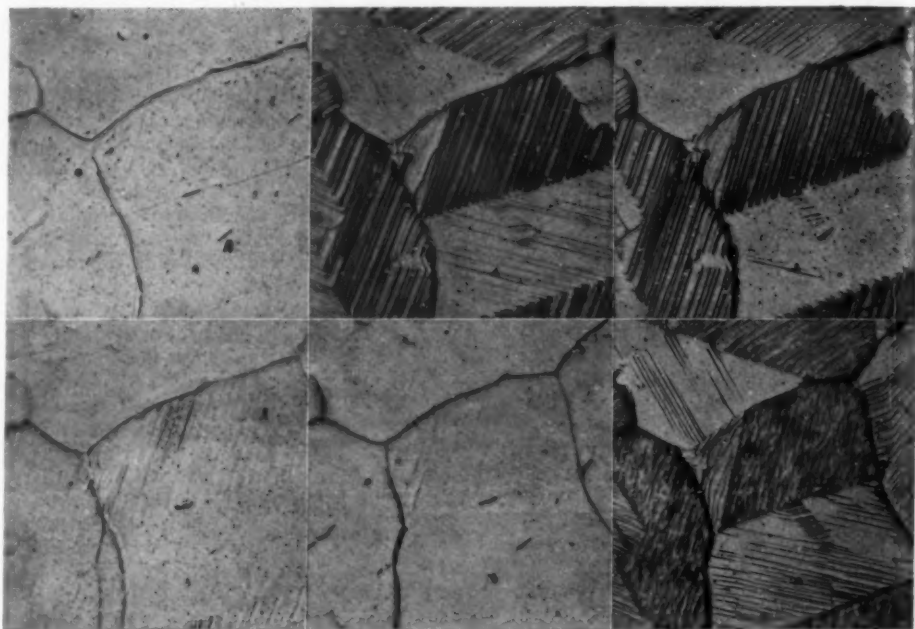
³⁰ Mrowca, *J. A. Phys.*, 1943, **14**, 684.

³¹ Leroux and Raub, *Z. f. Anorg. All. Chem.*, 1930, **188**, 205.

rate of oxidation of silver is negligibly small.^{32,33,34,35} They thus avoided complications due to the formation of an oxide film on silver. No confusion could arise from thermal fatigue phenomena, for silver is cubic and thermal stresses are not set up when it is uniformly heated or cooled. Lest the grooves be affected by impurities concentrated at the crystal boundaries they used silver of spectrographic purity which was cast in vacuum before being cold-rolled. As did Elam²⁵ for copper, they found that an important cause in the variation of the etching was the preparation of the surface and that even prolonged heating just below the melting point did not remove the effects of mechanical polishing. They eliminated this uncertainty by electrolytically polishing the cold-rolled silver;³⁶ this did not necessitate any preliminary grinding on emery paper and specimens prepared by this method etched in a reproducible fashion.

They heated specimens, 2 cm. square 8 S.W.G., in a silica tube that contained a controlled atmosphere. The required atmosphere was established in the tube before it was inserted into a furnace held at the temperature of the experiment, and maintained on withdrawal until the specimen had cooled to room temperature. They investigated the effect of atmospheres of: air, high purity nitrogen, a vacuum of 10^{-4} mm., and hydrogen, on specimens heated to 920° C. At this temperature the silver rapidly recrystallised, and later considerable, grain growth occurred. In air, boundary grooves were formed and striations appeared. Similar results were obtained on heating in oxygen at atmospheric pressure, but then the striations were more closely spaced and frequently a second set, and sometimes even a third, appeared in directions inclined to the first. The recrystallised silver was extensively twinned and the striations changed their directions where they intersected the rectilinear twin boundaries, this gave rise to patterns of great complexity. A number of photomicrographs typical of these patterns have already been published,^{2,3,36} and Fig. 3 ($\times 1500$) is a further series showing the surface of silver after it has been heated at 920° C. for 17 hours in oxygen at atmospheric pressure.

(a) Nitrogen 11 hours. (b) "a" after 1 hour in air. (c) "b" after 1 hour in nitrogen.



(d) "c" after 2 hours in nitrogen. (e) "d" after 8 hours in nitrogen. (f) "e" after 1 hour in air.

Fig. 1.—The reversibility of striations, 920° C.

$\times 250$

Specimens heated in nitrogen developed grooves at the crystal boundaries Fig. 1a ($\times 250$), but no striations appeared. At the boundaries between two twinned crystals, the grooves were usually much less distinct, however, occasionally they were as distinct as were the boundaries between independent crystals. It seems that when the twin boundary is the octahedral twinning plane, in which there is a plane of atoms common to each twin, the groove is indistinct. When the boundary between the twins is arbitrary the groove develops to the normal depth. This is well illustrated in Fig. 1a, the two octahedral planes of a twin are indistinct, whilst the arbitrary boundary A is plainly visible. A similar effect was found by Lacombe³⁷ on aluminium etched with a mixture of aqua regia and hydrofluoric acid.

Grooves, but no striations, appeared on specimens heated in a vacuum. After only 90 minutes at 920° C., because of considerable evaporation, the surface became rough and pits developed in the centre of many crystals.

Experiments were carried out to discover whether the striations formed by heating silver in the presence of oxygen could be made to disappear on reheating in nitrogen. A specimen was first heated for 11 hours in nitrogen at 920° C. until grain growth was proceeding only slowly and the positions of the boundary grooves were almost stationary, Fig. 1a ($\times 250$), it was then heated for a further hour in air at the same temperature in order to develop the striations, Fig. 1b. On changing the atmosphere back to nitrogen, the striations gradually disappeared over a period of eight hours, Figs. 1c, d, e; on reheating in air, the striations reappeared having the same directions as before, but were more closely spaced, Fig. 1f. The appearance and disappearance of the

32 Lewis, *J. Amer. Chem. Soc.*, 1906, **28**, 139.

33 Keyes and Hara, *J. Amer. Chem. Soc.*, 1922, **44**, 479.

34 Benton and Drake, *J. Amer. Chem. Soc.*, 1932, **54**, 2186.

35 Benton and Drake, *J. Amer. Chem. Soc.*, 1934, **56**, 255.

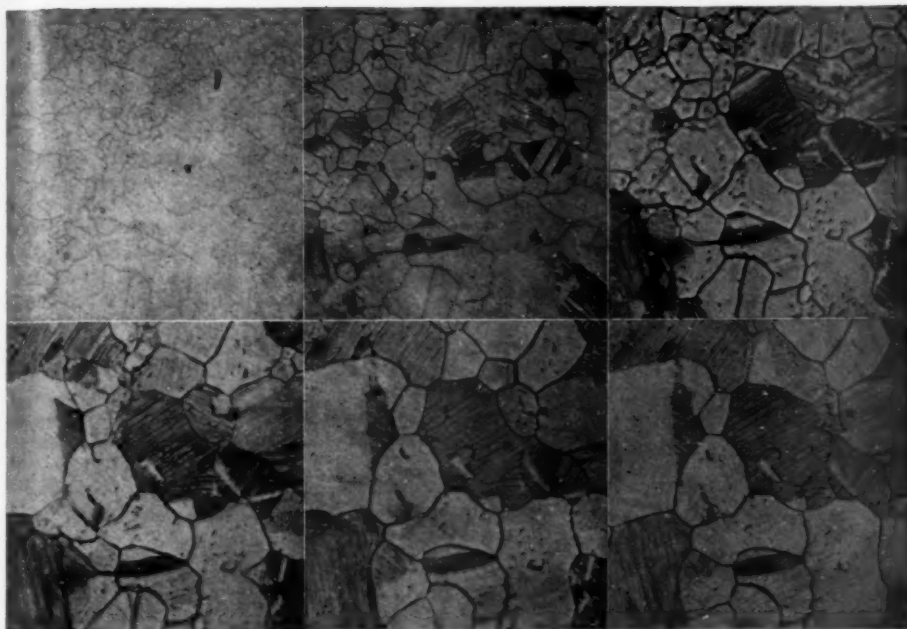
36 Shuttleworth, King and Chalmers, *Metal Treatment*, 1947, **14**, 161.

37 Lacombe, *Proc. Phys. Soc.*, 1948 (In course of publication).

(a) 8 minutes

(b) 1 hour

(c) 7 hours



(d) 17 hours

(e) 27 hours

(f) 36 hours

Fig. 2.—Grain growth in silver heated in air at 870° C.

×50

striations when the atmosphere was changed was reversible and could be repeated a number of times. In the course of other experiments it was noticed that when the silver was heated in air resting on a piece of "Immaculate" heat-resisting steel, the striations developed but began to fade after about 90 minutes and finally disappeared. This is not understood.

As the striations appeared to be the development of specific crystallographic planes on the surface an attempt was made to discover their indices. A specimen was heated first in nitrogen to 920° C. until grain growth was proceeding only slowly, and then in air for a short time to produce striations. A selected field was photographed, and the specimen heated in nitrogen until the striations disappeared; the specimen was then squeezed in a vice to develop slip lines and the selected field re-examined. In some crystals there was more than one set of slip lines, but in all cases there was one set parallel to the striations produced by thermal etching. As the slip lines are the intersection of the {111} planes with the surface, it is reasonable to suppose that the faces of the steps causing the striations are {111} planes. This result is in disagreement with the work of Graf¹², who identified the faces as {100} planes. However, Leidheiser³⁸ heated a silver single crystal in air, and in hydrogen containing 0.5% oxygen, and found that the striations which developed were 111 planes.

In order to examine the effect of temperature on thermal etching, silver specimens were heated in air for 11 hours at 300°, 500°, 700°, 850°, and 940° C.; at 300° C. no striations had appeared and the grain boundary grooves were incomplete; at 500° C. the boundary

grooves were complete and striations had begun to appear on some crystals. The proportion of striated grains increased with increases of temperature, and above 850° C. nearly all the grains were striated. At the higher temperatures, the striations were more closely spaced and a second set of striations, inclined to the first, appeared on some crystals.

In all these experiments, although the crystal boundaries were moving continuously, the grooves always coincided with their instantaneous positions. This fact provided a convenient method for the study of grain growth in silver.

A certain area was photographed after various times of heating in air at 870° C.; Fig. 2 a, b, c, d, e, f (×50). After only a few minutes at this temperature, the boundary grooves appear, and after one hour the striations. During the initial stages of heating grain growth is rapid, but the velocity of crystal boundary movement decreases with time and the silver seems to be approaching a state of equilibrium.

When silver of commercial purity is heated in air, grain growth is retarded at the surface owing to the oxidation of impurities at the crystal boundaries. Chaston,³⁹ however, has shown that in high purity silver this does not occur, so that Fig. 2 is typical of grain growth in the centre of the silver. A microscope with a hot stage was devised and this enabled grain growth to be followed continuously at temperatures close to the melting point.³ A 16 mm. objective of 0.28 N.A. was used and the apparatus had a useful magnification of 200.

Theories of Thermal Etching

(a) *Boundary Grooves.*—In 1912, Rosenhain and Ewen²⁴ suggested that the grooves formed because atoms from the boundary metal evaporate more quickly than do those from the crystals; this theory has been accepted by most workers. Rosenhain and Ewen postulated that the metal crystals were joined by a layer of amorphous cement. This cement although it consisted of metal atoms, was supposed to have no regular structure but was analogous to super-cooled liquid; and similarly had a greater vapour pressure than the crystals. Strong support for this theory appeared to come from their own²⁴ and from Fonda's³⁸ work. For they found that

³⁸ Leidheiser (Private Communication).

³⁹ Chaston, *J. Inst. Metals*, 1945, **71**, 23.

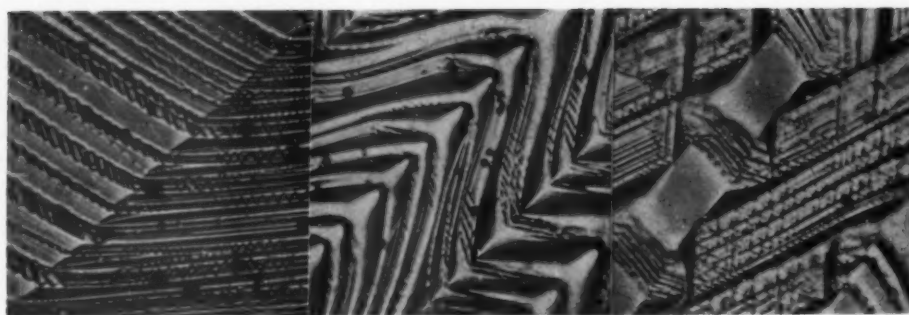


Fig. 3. Silver heated in oxygen at 920° C. for 17 hours.

× 1,500

when small grained metal was heated in vacuum the rate of loss of weight was about 50% greater than for large grained metal. They attributed this enhanced loss to the greater amount of amorphous metal exposed in the small grained specimen.

These arguments are not valid. If the metal at the crystal boundary is supposed amorphous the work of Kê⁴⁰ suggests that an appropriate model is that of a layer of super-cooled liquid, a few atomic diameters thick, say 10^{-7} cm. At a temperature $T^\circ\text{K}$ near the melting point $T_m^\circ\text{K}$, integration of the Clausius-Clapeyron equation gives for the ratio of the vapour pressure of the super-cooled liquid to that of the solid:

$$P_L/P_s = \exp \frac{F(1/T - 1/T_m)}{R}$$

Where F is the heat of fusion and R the gas constant. If the condensation coefficients of super-cooled liquid and solid are equal, the rates of evaporation will be in almost the same ratio as the vapour pressures. Even at temperatures well below the melting point, this ratio is not much greater than unity: for silver at 900° C., 60° below the melting point, the ratio is only 1.06. The small grained metal of Rosenhain and Ewen's experiments had a grain diameter of about 10^{-2} cm., so

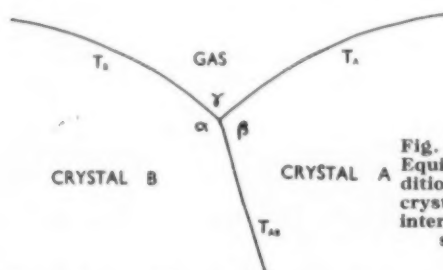


Fig. 4.— Equilibrium conditions where a crystal boundary intersects the surface.

that a layer of boundary cement 10^{-7} cm. thick would occupy but one fifty-thousandth of the surface area. To explain the experimental loss of weight on their hypothesis a vapour pressure ratio of 20,000 would be necessary. Nor can any importance be attached to the evaporation from the sides of the grooves once they have been formed; although more atoms evaporate the excess number condense on the opposite side of the groove.³

It would seem, therefore, that the enhanced loss of weight from small grained metal is not due to localised evaporation of boundary metal. An explanation might be sought along the lines of a crystal evaporating by

minimum free energy. Without considering any detailed picture of the crystal boundary, they attribute to it a certain free energy per unit area, which is analogous to the surface tension existing between two fluid phases. On this picture, in equilibrium, a groove must exist where the crystal boundary intersects the surface, for here three surface tensions meet along a line, Fig. 4. If T_A is the surface tension of crystal A, T_B that of crystal B, T_{AB} that of the boundary, the equilibrium angles α, β, γ between the three tensions are given by the triangle of forces

$$T_A/\sin\alpha = T_B/\sin\beta = T_{AB}/\sin\gamma$$

where α, β, γ are measured in a plane perpendicular to the line of intersection of the three surface tensions. While these conditions specify the angles at the bottom of the boundary grooves, their depths are controlled by the grain size. The equilibrium state is reached, when each grain surface is a convex cap of constant total curvature and intersects its neighbours at the equilibrium contact angles. The grooves which appear on polished surfaces, represent an intermediate state in this approach to equilibrium.

No measurements have yet been made on the angle γ at the bottom of the groove, but the photomicrographs indicate that it may be small enough to mean that the free energy of the boundary is comparable to those of the crystal surfaces. This is surprising as theoretical estimates of the energy of the crystal boundary place its maximum value at only one-fifth that of the surfaces. It seems that the surface energies of the surfaces (T_A and T_B) must have been reduced by adsorbed gases.

On this picture, it is clear why only shallow grooves appear at twinning planes, but deep grooves at an arbitrary composition plane separating two twins. At a twinning plane, there is only small atomic disorder for there exists a plane of atoms common to each twin, and such a plane should have only a small surface tension. At an arbitrary composition plane between two twins, the atomic disorder will be as great as between two independent crystals and such a plane will have the normal surface tension.

If evaporation of atoms into the vapour phase were the only process occurring, there seems no obvious reason why it should give rise to the equilibrium surface, and the small difference in the rates of evaporation of boundary and crystalline metal is insufficient to explain why the grooves reach a depth of about 10^{-3} cm. in a few hours. However, Andrade and Martindale⁴¹ have shown that the atoms or ions of silver are mobile over the surface at temperatures as low as 280° C. It is clear that

the stripping of atomic monolayers, this process being nucleated at the crystal boundaries. If this did occur it would not, of itself, produce boundary grooves.

Shuttleworth, King and Chalmers^{2,3} think that the surfaces, produced by thermal etching, are equilibrium surfaces of

40 Kê, *Phys. Rev.*, 1947, **71**, 535.

41 Andrade and Martindale, *Phil. Trans. Roy. Soc. A.*, 1935, **235**, 69.

the activation energy necessary for an ion to move from one position on the surface to another, will be much less than that necessary for an atom to evaporate into the vapour phase. When thermal etching occurs the ions on the surface must be supposed in a state of flux; more migrating away from the crystal boundary than towards it. Only when the equilibrium shape is reached do the flows in opposite directions become equal. That surface forces are sufficient to cause appreciable preferential migration is shown by scratching a groove with a pin on a piece of silver and heating to 870° C. The fine structure of the scratch disappears in about 20 minutes, and over a period of hours the scratch fills up until only a smooth and shallow depression remains. The evidence that the particles that migrate over the surface, carry a positive charge comes from the work of Johnson,²⁹ in which he showed that the form of the striations was influenced by the application of an electric field.

Although evaporation alone need not lead to the equilibrium form of the surface, evaporation combined with condensation must, for this is the spontaneous transfer of atoms over the surface. If the metal is surrounded by an inert gas evaporating atoms are reflected back and this mechanism should lead, but more slowly, to the same boundary grooves as does surface migration.

(b) *Striations.*—Leroux and Raub³¹ having found that silver heated in oxygen (but not in hydrogen) showed a loss in weight, attributed the formation of striations to the slower rates of oxidation in certain crystallographic directions; the oxide subsequently evaporating in molecular form. Elam,²⁵ finding that striations occurred on copper only in the presence of oxygen, advanced a similar explanation. Shuttleworth, King and Chalmers²³

found that the appearance and disappearance of the striations on silver was reversible when the atmosphere was changed from oxygen to nitrogen. They, therefore, suggested that for silver in oxygen the striated structure is the equilibrium form of the surface and has the minimum free energy. They suppose that oxygen is preferentially adsorbed on specific crystal planes, and reduces their surface energy to such an extent that a stepped structure formed from these planes has a smaller total surface energy, despite its greater area, than a smooth surface.

Possible mechanisms for the appearance of the striations are: surface migration, evaporation and condensation of silver atoms, and evaporation and condensation of molecular oxide. The relative importance of these mechanisms is not yet fully understood. Surface migration should be most important when the distance between the striations is small and the ions do not need to move far in order to form them. When large facets develop, as on tungsten filaments heated by A.C. in argon,²⁹ evaporation and condensation of atoms is probably most important.

It can be seen from this review that the amount of systematic experimental work on thermal etching is small, and that theories of the various phenomena are only tentative and require detailed elaboration. It would seem that the subject is worthy of further study, but that even in its present state it could often be applied to the solution of day to day metallurgical problems.

The author is grateful for discussion with Mr. G. Farrar. The photomicrographs were made by the author whilst at the Royal Aircraft Establishment; they are Crown copyright reserved and are reproduced here with the permission of the Controller of H.M. Stationery Office.

Development of Inventions

By S. T. Madeley

Considerable changes are contemplated in obtaining the development and exploitation of inventions if the recently submitted Development and Inventions Bill is accepted by Parliament. Some of the important features are briefly summarised.

AS a result of investigation by a Committee appointed to study the subject, the Government has submitted to Parliament a Development of Inventions Bill. It is to be noted that, in its Report, the Board of Trade Departmental Committee on Patents also recommended that a body should be formed to develop and utilise inventions, when it would be in the public interest so to do.

The Bill deals with the constitution of the National Research Development Corporation, as the new body is to be called. It also covers financial matters relating to the Corporation, besides setting out the functions of the Board and its relationship to the Board of Trade. According to the Bill, the Corporation is to secure the development and exploitation of inventions resulting from public research, or from other sources which have undergone insufficient or no development or exploitation where there is a requirement thereof in the public interest. In addition, the Corporation is to acquire, hold or dispose of, or grant rights relating to such inventions.

New processes and new techniques are to be included in the inventions concerned, and any research carried out wholly or partially by means of public funds is defined as "public research." The Corporation is to have the power to carry on, promote or facilitate such activities as business by itself or its agents, provided that activity is regarded as advantageous or convenient.

There are to be a chairman and a managing director and four to ten members in the Committee appointed by the Board of Trade. These members are to be experienced and capable in matters relating to science, technology, industry, finance and the administration or acquisition and the disposal of inventions. Exercise of the functions of the Corporation is to be so carried out that, taking one year with another, the Corporation will pay its way, so far as is consistent with the fulfilment of its purposes.

The Corporation is to comply with the directions which the Board of Trade may give to it, and is to obtain the approval of the Board subject to such conditions as the Board desires, before agreeing to carry out or

carrying out any project for making goods, constructing works, providing services or setting up any organisation for carrying out the project, financially assisting in the development or exploitation of any invention, or acquiring an undertaking or an interest therein.

Information is to be furnished when required to the Board by the Corporation about its properties and activities, and that body is also to make annual reports to the Board, setting out, amongst other things, directions given by the Board to the Corporation unless it would be prejudicial to the national interest. Copies of these reports are to be laid before Parliament.

Losses or estimated losses arising out of projects in response to representations by Government Departments in the public interest may be financially provided for by the Minister in charge of the Department with the consent of the Treasury. The Corporation may, with the approval of the Board, borrow temporarily up to an aggregate, which is not to exceed £250,000 outstanding.

To provide for initial expenses and working capital the Board may advance to the Corporation up to an outstanding aggregate of £5,000,000 within five years of the establishment of the Corporation. Under direction of the Board and with approval of the Treasury, the

Corporation is to repay advances to it and to pay interest on outstanding amounts. Interest may be waived within five years of the establishment of the Corporation. Statements of unpaid amounts due to the Board are to be laid before Parliament.

A reserve is to be established by the Corporation and to be managed as determined by the Corporation under direction of the Board. Proper accounts and records relating thereto are to be kept by the Board and an annual statement thereof is to be prepared and so much of them as can be made public without injury to the public interest are to be laid before Parliament.

Out of the Consolidated Fund, or the growing produce thereof, money may be issued by the Treasury to the Board with which to make advances to the Corporation. The Treasury may raise money under the National Loans Act 1939 to provide money for the Corporation. Repayments and interest to the Board are to be paid into the Exchequer and applied to paying off debt or paying interest as the case may be, and accounted for by the Board. These accounts are to be examined and certified by the Comptroller General and laid before Parliament.

A Schedule to the Bill contains provisions relating to the constitution and so on of the Corporation.

A Multi-point Furnace Control Panel

By C. L. M. Cottrell, B.Sc.

British Welding Research Association, London

When several furnaces are installed and only a few may be in use simultaneously, it is economical to group together a small number of controlling and recording instruments so that any furnace which is to be used can be easily connected to any one of the instruments. A method of achieving this is described.

IN research laboratories where varied heat-treatment and melting processes have to be carried out, the need arises for a number of different types of furnaces, some of which may have very specialised applications, and for that reason may be used only intermittently.

Since the most efficient method of maintaining a furnace at its working temperature is by means of an electrically operated controller (or controller-recorder if a record of the process is needed), it is usual to fit each furnace with its own control device. It is apparent that this method is expensive if it is carried out in laboratories where several furnaces are installed, but where only a few may be in use simultaneously.

A means of achieving the same result at a much smaller cost is to group together a small number of controlling and recording instruments, each one of which can be easily connected to any furnace which it is desired to use. This method has been adopted in the metallurgical laboratories of the British Welding Research Association and a panel has been built which has proved itself to be most efficient in operation.

Description of Furnaces to be Controlled

In the B.W.R.A. metallurgical laboratories provision is made for controlling and/or recording the temperature of the following apparatus:—

- (1) An electric muffle furnace, for the heat-treatment of low-alloy steels, operating up to 1,000° C.
- (2) A drying oven for baking welding electrodes at temperatures up to 200° C.



Fig. 1.—General view of the complete panel.

- (3) A salt bath for the heat-treatment of light alloys.
- (4) A forced air circulation furnace, for the heat-treatment of light alloys, operating up to 550° C.

- (5) A gas-fired crucible furnace for melting, fitted with an electrically operated control valve.
- (6) Other special research equipment.

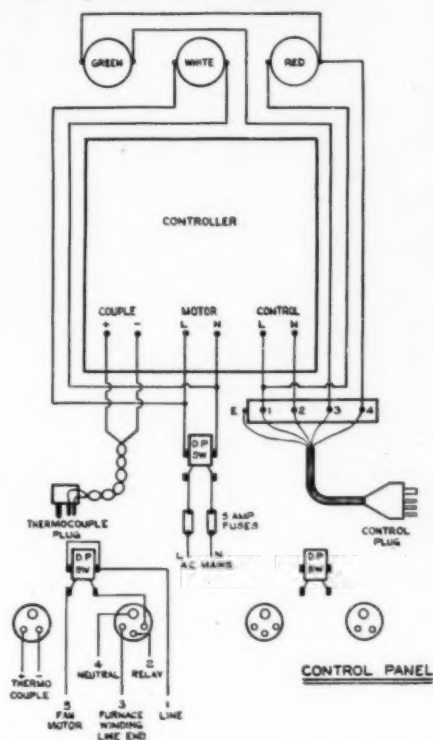
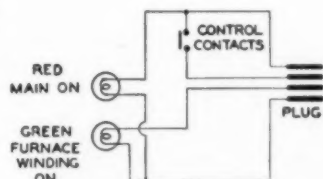


Fig. 2.—Wiring diagram for one control unit.



Controlling and Recording Instruments

Three main instruments are used since only rarely will more than three furnaces be in use at any one time. They are: a 0–700° C. controller, a 0–1,300° C. controller and a special purpose controller-recorder having three millivolt ranges of 0–15 mv., 14–29 mv. and 28–43 mv., the two latter ranges being obtained by means of a dual suppressed zero unit.

The two controllers are calibrated for Chromel/Alumel thermocouples. The controller-recorder can be used with both Chromel/Alumel and platinum/platinum-rhodium thermocouples; when used with the former the scale is very open for precise heat-treatments from 0–1,000°C. The recording chart is numbered for all three ranges of millivolts, each having its own code colour which corresponds to the dotting colour. It is thus easy to see at once on which range the instrument is operating.

In addition to the three main instruments, energy regulators can be used if at any time more than three furnaces are in operation.

Panel Layout

Fig. 1 shows the control panel with the controller-recorder in the centre and two controllers on either side.



Fig. 4.—Mechanism behind the panel for returning plug to the panel face.

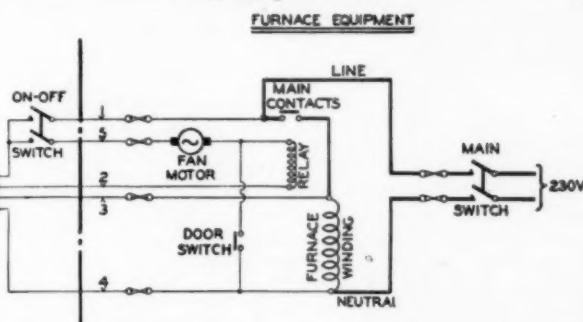


Fig. 3.—Wiring diagram showing connections to a furnace fitted with an air-circulating fan.

Below the instruments are the necessary plugs and sockets.

Three indicator lights coloured red, white and green, are situated above each controller. The red light indicates that the power supply is connected to the apparatus under control and the green light shows when the furnace heater is on. The white light indicates that the controller is switched on.

The control leads from each furnace are brought to a four-pin socket on the panel as shown in Fig. 2 and Fig. 3. These sockets, one for each furnace, are numbered with their appropriate furnace number. The control leads from each controller and set of signal lights terminate in a four-pin plug which is connected by means of a five-core cable, one wire of which is earthed and connected to the metal plug body.

The thermocouple compensating leads from each furnace are brought to three-pin sockets, each of which is situated alongside the related control sockets. Copper leads are used only for any special apparatus with a cold junction by the furnace; in all other cases the cold



Fig. 5.—Energy regulator connected to the panel for controlling a furnace.

junctions are at the panel. The resistance of the thermocouple leads to each furnace is balanced behind the panel to four ohms. The thermocouple leads from the controllers terminate in three-pin plugs, two pins only being connected, while the third pin makes the plug irreversible and ensures a correct connection. A panel wiring diagram for one furnace point and one controller is shown in Fig. 2 and the connections to a furnace in Fig. 3. The leads from all the plugs are carried over pulleys and are weighted so that the plugs return to a position at the panel face when not in use. The pulley mechanism behind the panel is shown in Fig. 4.

An energy regulator is shown attached to a control socket on the panel in Fig. 5. This is a standard type of energy regulator with a special three-pin base fitted so that its heating coil is between lines 1 and 4 and its contacts between lines 1 and 2.

National Foundry College

THE National Foundry College has opened for its first post-war session with 18 students from the United Kingdom and overseas, and is housed in the Wolverhampton and Staffordshire Joint Technical College. The next session will open on 27th September, 1948, and will continue until the end of July, 1949. It is confidently expected that by the time the next session begins a hostel will be available for the use of students. Those interested in the Course can obtain a form of application for admission, together with the Prospectus and Curriculum from the Head of the College, Mr. J. Bamford, B.Sc., at the Technical College, Wulfruna Street, Wolverhampton. The Board of Governors of the College is now complete, under the Chairmanship of Mr. Randall G. Hosking, C.B.E., and the attached list gives the members of the Board and the Institutions they represent.

Recommendations for the Design of Arc Welded Mild Steel Machinery Construction

In the design of welded constructions the view has often been expressed, correctly so, that it is essential to take full account of the special features introduced by the use of welding, and that the designer should not adhere rigidly to principles that have been established for other methods of construction if the most efficient and economic unit is to be produced.

It is inevitable, in some measure, that a comparison should be drawn between the requirements of welding and those of casting or riveting, particularly where the part under consideration has previously been made by one of the latter methods. This tendency is largely due to the accumulation of extensive practical experience in the older fields of construction and to the lack of published information of welded design.

The formulation of general design rules for welded machinery constructions presents a particularly difficult problem. A variety of components of complicated form may be involved in any one application, and the effects of boundary conditions and continuity in the structure, from the point of view of stress analysis, cannot be easily assessed.

During the past few years, however, some experience has been gained in the design and fabrication of welded machinery foundations and parts, through the stimulation provided by war-time needs. It is the object of this memorandum to present, in a concise and usable form, a detailed outline of recommended practice based on this experience and knowledge.

The memorandum is sub-divided into the following general sections: (a) Fillet and Butt Welds; (b) Working Stresses; (c) Design and Details; (d) Information Required for Manufacture.

Each section has been prepared in order to provide the information required at the various stages in design and manufacture. In addition, to giving necessary guidance on these aspects of welded machinery construction, the complete memorandum has been drafted in a form similar to a code of practice so that it may be readily applied in drawing up specifications for this type of work.

The work described in this report has been carried out for the FE. 7 Committee (on Design of Welded Machinery Constructions and Parts) of the British Welding Research Association.

New Material for Vehicle Castings

Examples of rear axle castings, hubs, manifolds, differential cages and carriers used in the commercial vehicle industry were among the exhibits of Hale and Hale (Tipton) Ltd. at the recent Fair at Castle Bromwich. From small beginnings this firm has grown into one of the two largest malleable iron foundries in Britain. It is noteworthy that its laboratories are at present developing a new high duty alloy material known as Permalite, which tests prove to be ideal for the production of brake drums, gear blanks, heavy lifting jacks and all castings requiring to resist hard wear and abrasion. The new material has a tensile strength in the region of 33 to 35 tons per square inch and a yield strength of 21 tons per square inch, compared with 22 tons tensile and 12 tons yield, for the best quality blackheart malleable iron.

The Absorptiometric Determination of Chromium in High-Speed Steels by Sodium Chlorate Oxidation

By F. E. Eborall, A.Met., A.I.M.

Chemical Laboratory, Geo. Senior & Sons, Ltd.

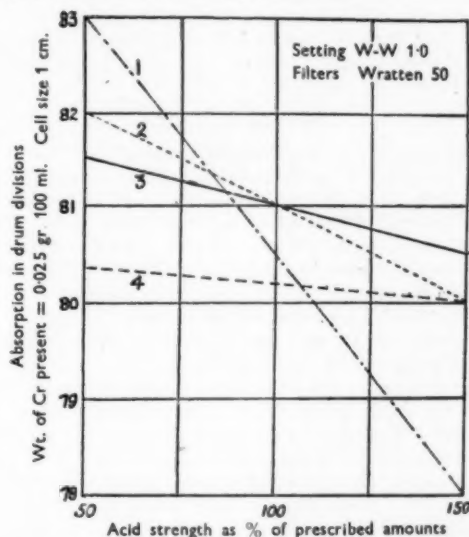
Sodium chlorate is employed in the method to oxidise iron, tungsten, carbides and as a quantitative oxidant for chromium. Manganese partially oxidises to manganese dioxide. Improved decomposition of the carbides is obtained as compared with nitrate oxidation. Tungsten and manganese dioxide are eliminated by filtration. Vanadium, molybdenum, nickel and cobalt can be determined as in the compound method previously published.¹

FOLLOWING the development of the compound method referred to above, research was undertaken with a view to simplifying the procedure and improving the efficiency of the methods. Attention was turned to the chlorates as oxidising agents. Potassium chlorate was found to give satisfactory oxidation of the tungsten and any carbides. Chromium oxidised to dichromate on evaporation and this oxidation was found to be quantitative. However, potassium perchlorate, formed during the evaporation, was found to be comparatively insoluble. Sodium chlorate was then tried and the insoluble perchlorate did not form, owing to the higher solubility of sodium salts. Investigation showed that, in order to separate all the tungsten from solution, evaporation prior to oxidation was essential. This evaporation was also effective in decomposing the majority of the carbides. Vanadium was oxidised to the pentavalent form and was not subsequently reduced on fuming. No effect was found from residual chlorine or chlorides.

The oxidation is carried out in sulphuric acid solution at boiling point. On the addition of sodium chlorate to the dissolved steel, the iron oxidises immediately, followed by the tungsten. On evaporation, the chromium oxidises and decomposition of the carbides, if not already complete, proceeds. When the chromium is fully oxidised, a portion of the manganese becomes oxidised to manganese heptoxide which, being volatile, is emitted as a gas and dissolves in the drop of water suspended from the cover glass to give rise to the "pink drop" effect. The formation of this pink drop is an indication that the chromium is fully oxidised. Absence of this effect does not imply incomplete oxidation since any spray collecting on the glass during "bumping" will tend to mask or destroy the colour.

The behaviour of the manganese as outlined above renders the method inoperable on steels not containing much tungsten. The presence of tungsten is necessary in order to coagulate the manganese dioxide formed when the permanganic acid is refluxed into the solution and decomposes. It has been found impossible to filter out this manganese dioxide by means of asbestos, in the absence of tungsten, and the colloidal form gives high figures for chromium. In the presence of tungsten, this colloidal form does not exist to any marked degree. Should procedure be worked out to destroy this manganese dioxide by dilute hydrochloric acid or other means, there is no reason why this method of oxidation by chlorate should not be of use on all classes of steels, both for absorptiometric and volumetric methods.

The presence of chromium as dichromate renders the use of a non-reducing filter medium necessary. Asbestos fibre is at present in use. Should it be required to deter-



1. Sulphuric acid.
2. Spekker acid.
3. Sulphuric acid in presence of 6ml. phosphoric acid.
4. Phosphoric acid.

Fig. 1.—The effect of variation in acid strength on the absorption due to dichromate solutions.

mine any of the other elements specified, the presence of dichromate has very little effect. Vanadium can be determined by the hydrogen peroxide method, chromium being simultaneously reduced. Dichromate forms a complex with Nitroso-R salt, but this is of a very small order compared with that formed by cobalt. If desired, the chromium may be reduced with ferrous ammonium sulphate prior to the addition of Nitroso-R salt, the complex then not being formed. In the determination of molybdenum, the dichromate is reduced by the stannous chloride and sufficient of the latter is normally present to effect this reduction. No interference has been found in the case of nickel. Chromium and vanadium are determined on the same fraction and the remaining elements as under the compound method referred to above. The corrections given under that method are still applicable with the exception of that for manganese on chromium, which, of course disappears. For obvious reasons, manganese cannot be determined. Adsorbed vanadium and molybdenum are determined as before.

The absorption of light by a dichromate solution is dependent, to a certain amount, on the acid strength of the solution. This fact is often cited as an objection to

¹ A Compound Method for the Absorptiometric Analysis of High and Super High Speed Steels, Eborall, *Metallurgia*, Dec., 1946.

the absorptiometric determination of chromium. In order to investigate the precise effect of this variation, a standard dichromate solution was treated with varying amounts of sulphuric and phosphoric acids and the absorption figures plotted in Fig. 1. It will be seen that, for a given amount of phosphoric acid, as present in the method, variation of the sulphuric acid concentration from 50–150% of the prescribed amount produced a variation of only 1% in the absorption figure. This diversity of acid strength far exceeds that to be found in routine work. The amount of sodium chlorate which could be added without producing any interference was studied and up to four times the prescribed amount was added without deleterious effect.

This compound method is in daily use in this laboratory and several hundreds of determinations have been made on all classes of high-speed steels. The accuracy and reproducibility of the results have been found to be very good and tests against the standard methods have shown the method to be reliable.

Procedure

Solutions required:—20% sulphuric acid.

16% aqueous sodium chlorate.

0.5% aqueous ammonium sulphate.

Take 0.5 gr. of the steel and treat with 30 ml. 20% sulphuric acid, in a 200 ml. conical beaker. Pyrex or Hysil beakers are recommended. Place the covered beaker on the hot plate and raise the contents to a boil. Digest until all effervescence has ceased. Evaporate to strong fumes of SO_3 and continue fuming for 5 minutes. Remove from plate, cool, re-dissolve with 15 ml. of water and raise to the boil. Place on a cool portion of the plate and add 5 ml. of the sodium chlorate solution. Digest until the tungsten is fully oxidised and then raise to a gentle boil. Evaporate steadily until the bulk approaches 10 ml. Should the cover-glass be contaminated due to "bumping," it is recommended that the adhering drop be drained into the main solution. As the bulk approaches 10 ml. manganese heptoxide will be emitted as will be seen by sudden eruptions of the liquid and, if the cover-glass is clean, the appearance of a "pink drop". Should this not appear, evaporation should be suspended when evolution of the heptoxide has been proceeding for 2 or 3 minutes. The solution is allowed to cool slightly and 30 ml. water added. The beaker is returned to the plate and the contents *carefully* raised to the boil.

An asbestos pad is prepared of fibre which has been treated so as to have no reducing power. The boiling solution is filtered into a 200 ml. beaker and the pad washed with 0.5% ammon. sulphate solution. When washing has been completed, 6 ml. of phosphoric acid are added to the solution which is then cooled and diluted to 100 ml.

If molybdenum or vanadium are to be determined, 10 ml. of 5% caustic soda are added to the original beaker, the tungsten dissolved and the caustic solution passed through the pad to dissolve the tungsten thereon. Beaker and pad are washed with the ammonium sulphate solution and the washings collected in a fresh 200 ml. beaker. The resulting solution is acidified with phosphoric acid, adding 1 ml. excess, diluted to 50 ml. and reserved for the determination of the adsorbed vanadium and molybdenum.

Determination of Chromium

The Spekker absorptiometer is set at W-W 1.0 using

Wratten 50 or Ilford Violet 601 filters and a 1 cm. cell. The cell is now filled with the chromium solution and the absorption determined. This is converted to % chromium from a graph made as below. The mercury vapour lamp is used as light source and direct methods of reading are applied. Corrections for vanadium and cobalt (if present) are required.

Preparation of the Graph

Owing to the formation of potassium perchlorate during the evaporation it is inadvisable to use the standard method of graph preparation—i.e., adding known amounts of potassium dichromate to an iron solution and proceeding with the method. Chromium sulphate should be used instead. An alternative method is to prepare the necessary solutions of H.H.P. iron and add dichromate solution following the oxidation with sodium chlorate and subsequent cooling. 0.4 gr. iron/100 ml. should be used to allow for the tungsten present in high-speed steels.

Determination of Vanadium

If the determination of the vanadium is required, following the determination of the chromium and the taking of any other fractions required, an analoid of Hyperol should be added to the solution. After 15–20 minutes the vanadium will be fully oxidised to the pervanadate and the determination carried out by the normal absorptiometric method.^{2,3} The amount of adsorbed vanadium should be also determined.

Determination of Cobalt, Molybdenum and Nickel

The procedure outlined in the previous compound method should be applied. The tendency of dichromate to form a complex with Nitroso-R salt has been referred to above.

Acknowledgment is due to the Directors of Messrs. Geo. Senior & Sons, Ltd., Ponds Forge, Sheffield, for permission to publish this paper and to Mr. D. Spilsbury, for his assistance in the investigation.

² Monographs by Vaughan, E. J., M.Sc., F.R.I.C., Royal Inst. of Chemistry.
³ Haywood and Wood, *Met. Analysis*, Hilger, 1944.

Laboratory Ware

A new list of pure fused silica ware is now available. It comprises 48 pages, and is divided into three sections—viz., general apparatus, solid fuel analysis, and special methods of analysis. It also includes useful information concerning some of the more important properties of Vitreosil. As is generally known Vitreosil is a contraction of vitreous silica. It consists of pure silica, fused into a thoroughly pure, homogeneous and uniform product, containing over 99.8% SiO_2 , and possessing remarkable properties of great value for scientific and technical purposes, particularly where heat or acids are involved. It is manufactured in both translucent and transparent varieties. The former is suitable for ordinary laboratory and experimental purposes where transparency is unnecessary. The latter is not only transparent to visible light, enabling the progress of a reaction to be followed, but it also transmits ultra-violet rays and is thus invaluable in connection with radio-therapeutic, monochromatic and ultra-violet light apparatus. This list gives full particulars and prices of laboratory ware available in this material and supersedes all previous editions. Copies are available from The Thermal Syndicate, Ltd., Wallsend, Northumberland, England.

The British Iron and Steel Industry

A Review of Progress and Policy

Of late there has been a tendency to criticise the efforts of the iron and steel industry of this country without taking into consideration conditions as they existed following the 1914-1918 war, or the efforts made before and during the recent war to increase output and improve its quality. For some inexplicable reason reference to the fact that the Iron and Steel Board was established in 1946 does not appear to be recognised; yet this public Board is responsible to the Ministry of Supply for prices, production and future development in the industry. Another fact which seems to be ignored is that the industry has set up the largest research organisation in the country. In this article an effort has been made to interpret conditions during the inter-war period, the effect of reorganisation schemes put into operation during a period of depression, and the developments made since 1945. It is suggested that the present public control of the industry is functioning successfully and that it would be unwise to experiment in the public ownership of such a complex industry until success has been achieved in other, less complicated, industries taken over by the Government.

THE British iron and steel industry has a great heritage in a reputation for quality and is continuing its endeavours to further increase its renown as manufacturers of the highest-quality products. In the past Britain was also in the forefront in respect of the quantity of iron and steel produced, but for many years her production has been surpassed by a number of countries more favourably placed for raw materials and whose domestic requirements for iron and steel make greater demands on their manufacturers. It should be remembered, however, that the iron and steel industry of the world is still largely based on early developments initiated in this country. Since those early days development of the industry in Britain has fluctuated but in the main it has continued to progress, and there is no indication of sterility or decay in its make-up today; indeed, it is probably more progressive than at any previous time in its long history and production is at higher levels than have hitherto been reached. Yet for some inexplicable reason the great efforts of the industry are being criticised by responsible Government Ministers and others.

The industry is blamed for not supplying steel to meet the export targets originally set in an effort to establish a balanced economy. The statement has even been made that the industry should have doubled its capacity in the period between the two wars; yet during that period the industry was blamed for the violent fluctuations in demand and the under-employment of steel capacity, which was frequently experienced in this country, and also abroad.

Conditions During the Inter-War Period

The conditions prevailing in the iron and steel industry at the end of the 1914-1918 war should not be overlooked if there is an honest desire to examine the industry in its right perspective. The eminence of the British industry was built up on cheap fuel conditions, when no economic advantage could be gained by the expense involved on plants necessary to save fuel. Market requirements for its products varied so much that mass production of standard materials could only be adopted to a limited extent; in consequence it was not easy to reproduce results of fuel efficiency per ton of product such as were obtained at foreign plants operating on mass production lines.

Conditions on the Continent were not nearly so difficult as in this country. Many plants in these

countries were entirely destroyed during the war and complete re-building was necessary, while the inflation policy adopted in certain countries reduced the charges on existing plants to negligible proportions and made it easier to obtain new equipment. Lower wages in these countries, together with depreciating currencies, stimulated their exports and enabled plants to operate at relatively high capacity, resulting in high fuel and production efficiency. In Germany, for instance, the deflation in currency enabled industry to obtain cheap labour and materials, and by borrowing a large amount of capital abroad, was able to conform to the requirements of the Versailles Treaty to organise her industries to meet peace-time conditions.

The position was very different in Britain. Apart from some outstanding examples, complete re-organisation to the same extent as on the Continent was not attempted, with the result that in a restricted market British manufacturers suffered. Britain at that time, faced her responsibilities abroad too readily and failed to give that attention to domestic problems which were of equal importance. The stabilisation of the pound imposed a severe strain on the financial structure which curtailed reconstruction and the installation of new plant. It is not surprising, therefore, that the British iron and steel industry, working with high labour costs, heavy transport charges, and heavy taxation, found its competitive power reduced to such an extent that its productive efficiency was seriously impaired.

Formation of a National Committee.

At that time the iron and steel industry experienced a period of depression which grew in intensity until, in 1932, a National Committee was appointed to report on the industry and to devise a scheme of reorganisation. Leaders of the industry had approached successive Governments with a plea for protection to combat the menace of the dumping of foreign steel, which, they submitted, was essential if the iron and steel industry was to survive. The then National Government granted protection for a limited period, which was subsequently extended for two years, but the Government stipulated, through the Tariff Advisory Board, that in return for this protective duty the industry must put its house in order and supply the right material at the right price. With the report was coupled a scheme, submitted by the National Committee, for the reorganisation of the industry.

The purpose of the National Committee was to build comprehensive machinery for the industry within which the advantages of combined action and individual enterprise could be secured. It was with respect to this machinery that the scheme was primarily concerned. The scheme, it will be remembered, embraced the formation of twelve associations, each concerned with a group of products co-ordinated by the formation of a national body to be organised so as to give reasonable balance of interests to the producing and consuming sections of the industry.

At that time, undoubtedly, the stage was set for the more complete nationalisation of this vital industry at some future date, and we commented on this aspect fifteen years ago. Considerable divergence of opinion was expressed by those concerned with the industry with regard to the merits and demerits of Governmental intervention and control. As would be expected the majority of steel firms did not believe that Government control was necessary or that it would be beneficial to the country. It was generally agreed, however, that co-operation with the Government was essential, but that the industry itself should work out its own salvation and re-establish itself on a sound basis, so that the Government could have every confidence in it should the country be in danger at any time. As suggested by Mr. Charles Mitchell, who was then Chairman of the National Committee, the machinery set up would in course of time, function as the hub of the wheel of the British iron and steel industry, and in due course of the Empire. His view was that the iron and steel industry should itself use this machinery to make the industry a strong and effective organisation, co-ordinating the various sections of the industry within itself and by itself, presenting a united front to foreign competition, and enabling it to compete successfully in the available markets of the world.

With the imposition of import tariffs on iron and steel, the industry began to make headway, but the first draft reorganisation scheme submitted by a special committee of the British Iron and Steel Federation was not acceptable, however a shadowy scheme was accepted in principle and another committee was formed to give effect to amendments and to take into consideration further suggestions. Ultimately, a scheme was decided upon and put into operation, the scope of which embraced the need for concentrating and perfecting production and on reorganised marketing.

Emerging from Depression.

But even in 1932, as shown by the output of ingot steel, there was evidence that Britain was emerging from the world depression in advance of other countries, and the improvement continued. By the end of 1934, the policy of protection had brought about a marked recovery. During that year pig iron production increased about 50% and the production of steel about 20%. Exports also showed a welcome increase, during the latter few months of that year being at the rate of 25% higher than in 1933. And, in view of criticisms regarding prices and profits, it is important to note that the price level was only 10.1% above the 1913 level, despite the fact that the general wage level of the country was 64% above the 1913 level, and many of the contributing costs of the industry, such as transport, coal and other materials, were substantially higher than in 1913. Certainly, the Federation could claim this to

be striking testimony to the progress made in production efficiency at that time.

Even during the most difficult period of the depression, a number of progressive firms had put into operation reorganisation schemes and, following the acceptance of a national scheme, further impetus was given to modernisation and reconstruction; by 1939 a considerable amount of plants could truthfully claim to be operating as efficiently as any plant in the world. Production of iron and steel was then nearing full capacity of the plant in operation, and, since the demand showed a tendency to increase, many companies extended their construction schemes or were contemplating further extensions. Some indication of the steel output is shown by the figure for May of that year which reached 1,218,100 tons, while the pig iron production for the same month was 692,100 tons. Thus, when a state of emergency arose by the declaration of war, the iron and steel industry was organised and equipped to give excellent service.

Service during World War II

Largely due to the building up of facilities to ensure greatly increased production of iron and steel, and in particular to the efficient manner in which the industry responded to the demands made upon it, steel production proceeded at peak levels. Not only was there a great demand for all grades of carbon steels, but there was a need for a great advance in alloy and special steels; especially was there a greatly increased demand for a wide range of re-rolling products. That these demands were almost wholly met by the industry in the face of unprecedented raw material difficulties, shortage of labour, black-out conditions and unpredictable changes in demand, sometimes imposed at very short notice by the urgent requirements of the war, should always be placed to its credit. In all, the iron and steel industry produced and handled a grand total of 86 million tons of steel during the war; of this 14 million tons was imported and the rest manufactured in this country. During this period the industry mined and used over 100 million tons of iron ore, mostly home ore of low iron content, and approximately 50 million tons of scrap, much of which was obtained from special collections. It should be noted that, during this period, the statistics covering the relationship of demand against supply show that in 1941 deliveries met 92.6% of allocations; in 1942, 96.1%; while in 1944, the figure was 98.1%. This is a record of which any industry might well be proud. It does not seem to support the criticisms levelled at the industry about outworn and out-dated plants.

During the war emphasis was continually on increased steel production, and by taking extraordinary steps, not only by building new plant, but by increasing the output from existing furnaces, by reducing the time per heat and increasing the number of heats before shutting down for repairs to lining or roof, the industry did a tremendous job of work to meet the nation's need. And the cessation of hostilities brought no respite to the industry; while demands for steel did in fact lag for a time, exports were boosted to compensate, thus there was relatively little time-lag for the change-over from war to peace-time production.

Modernisation and Reconstruction Plan

To meet this demand of further modernisation and reconstruction, a plan was immediately initiated by the

British Iron and Steel Federation and subsequently issued as a Government White Paper. The objects of the plan were to make good the further modernisation and development which would have taken place during the previous six years had there been no war; to enlarge steelmaking facilities to bring them into close relationship with anticipated demands for steel products; and to ensure the most effective use of plants by concentrating production into efficient units of appropriate size. The plan envisaged the building of $4\frac{1}{2}$ million tons of blast furnace capacity and about 6 million tons of steel ingot capacity; provision for the stepping up of the rate at which new building is initiated to about 40% of the industry's capacity in a five-year period.

The total expenditure of the modernisation and developments agreed upon at that time was £168 million and this was spread over the various producing centres, South Wales; North East Coast; Scotland; North West Coast; Sheffield; Lancashire, Flintshire, Staffordshire, etc.; Lincolnshire; and Northamptonshire; in conformity with the plan. But costs of equipment and plant have shown an upward trend and, in addition, modifications and extensions have been found necessary as a result of changed conditions, in consequence the total expenditure will undoubtedly exceed that originally estimated.

Development Schemes

Recently it was stated by the Minister of Supply in the House of Commons that 526 schemes of development of the industry had been examined and passed by the Iron and Steel Board, which was established by the Government in 1946. Some 69 schemes were undergoing examination, and it was expected that nine major schemes would be submitted during the remainder of 1948. Among the major schemes finally approved are: the installation of ore unloading plant; additions to coke ovens, ore preparation plant and services, the re-building of two blast furnaces and new melting shop, at the Margam Works of the Steel Company of Wales. A new coke-oven battery and an additional open-hearth furnace at the Ebbw Vale Works of Richard Thomas and Baldwins. Ore loading, crushing, screening and sintering plant on Tees-side, two new blast furnaces at Cleveland to replace obsolescent units, and a new steelmaking plant at Lackenby, for Dorman Long and Co., Ltd. A new coke-oven battery and provision for two modern blast furnaces to replace existing units at the Consett Works of the Consett Iron Co., Ltd. Replacement of blast furnace and reorganisation of steel making plant at the Saltburn Works of the Skinningrove Iron Co., Ltd. Additional coke-ovens and the provision of a third blast furnace at the Clyde Ironworks; and the conversion of furnaces to oil firing at Dalzell Works of Colvilles, Ltd. The reconstruction of the melting shop at the Clydesdale Works of Stewarts and Lloyds, Ltd. Replacement of a coke-oven battery at the Treeton Works of United Steel Companies, Ltd. The installation of a new open hearth furnace at Rotherham for John Baker and Bessemer. Blast furnace charging equipment at the Rotherham Works of the Park Gate Iron and Steel Co., Ltd. Erection of coke-ovens, a blast furnace and a new melting shop at the Shotton Works of John Summers and Sons, Ltd. A new melting shop at the Brierley Hill Works of Round Oaks Steel Works, Ltd. The rebuilding of two blast furnaces, installation of ore crushing, screening and

sintering plant and gas cleaning plant at the Chesterfield works of the Sheepbridge Coal and Iron Co., Ltd. The provision of ore preparation plant, an increase in coke-oven capacity, and a new open-hearth melting shop at the Corby Works of Stewarts and Lloyds, Ltd. A new coke-oven battery, the erection of two new blast furnaces, and a new melting shop at the Appleby-Frodingham Steel Co., branch of the United Steel Companies, Ltd. A new coke-oven battery, ore crushing plant, modernisation of existing blast furnace and erection of a new blast furnace, and the re-building and enlargement of steelmaking furnaces at the Scunthorpe Works of John Lysaght, Ltd. A new blast furnace to replace two existing units, ore handling plant and pig casting machines, and several other improvements at Richard Thomas and Baldwins works in Scunthorpe.

A considerable amount of work involved in these schemes has now been carried out, but it may be of interest to indicate in greater detail some of the work of rehabilitation in progress. Although it is only possible to give a few typical examples, they will form a guide to the extent of development work embraced by the schemes that have been put into operation or are contemplated.

Typical Examples of Work in Hand

Steel Company of Wales.—The decision to instal a three-stand cold-reduction mill at the Abbey Works, means that an additional building of 600,000 sq. ft. will be built east of the hot-mill finishing departments. The hot-reduced coils will be brought to this building by twin-cooling conveyors, 1,000 ft. long. This building will consist of five bays. The coil storage and pickling bay ($105 \times 1,400$ ft.). The annealing bay ($125 \times 1,000$ ft.). The mill bay ($105 \times 1,000$ ft.). The processing bay (105×840 ft.). The shipping bay (125×840 ft.).

The plant will consist of an 80-in. continuous pickle line with 4-80 ft. acid tanks and acid recovery plant. An 80-in. three-stand cold-reduction mill, each stand being driven by a 4,000-h.p. motor. The maximum finishing speed being 2,000 f.p.m. The mill will roll coils up to 30,000 lb. in weight, up to 72 in. wide and down to 0.026 in. thick. Annealing will be in coke-oven gas-fired portable cover-type furnaces. Part will be annealed in coil form and part in sheet form. There will be three skin-pass mills of the four-high single-stand type, one will skin pass in coil only, one in either coil or piece. One in piece only. There will initially be three coil cut up lines for shearing the coils into sheets. In addition there will be shears, oilers, levellers, circling machines and other small plant. It is estimated that the initial output will be 5,000 tons per week rising to 7,000 tons or more by the addition of further annealing plant.

As there are existing works at Margam and Port Talbot, which must be maintained on production until reorganisation is completed, one of the main problems has been that of keeping the plant in full operation, while reconstruction is taking place. Alternative rail tracks have had to be laid and drainage culverts and gas mains diverted to allow the new work to proceed. Provision has also to be made for the erection of the new ore transporters on the wharf without interfering with the existing transporters.

The site of the new wagon tipplers has been piled and tracks laid for the tippler sidings. Pile driving and preparation of pile caps has been practically

completed on the site for the new coal washery plant to be installed by the Coppee Company. Simon-Carves are busy with the foundations for the new coke ovens. No. 2 blast furnace has been dismantled and Ashmore, Benson, Pease, have in hand the erection of a new blast furnace with a 25 ft. 9 in. hearth diameter. Work is proceeding on the substructure of the bridges to carry the low level transfer cars along the whole length of the wharf. The rail beam of the ore transporter has been extended to permit the erection of the new transporters without interference with the existing transporters. Six new railway bridges are being constructed for British Railways, the completion of which will provide a new rail extension and permit an existing railway embankment to be removed to make room for a coal washery.

Stewarts and Lloyds, Ltd.—Schemes for post-war rehabilitation and expansion of this Company's works were included in the original report of the British Iron and Steel Federation to the Minister of Supply. Briefly, that plan provided for an overall increase in the tube capacity of over 25%, with a corresponding increase in steel capacity. The plan received official approval, and construction is in progress. Since that plan was made in 1944, it became apparent that the export demand for tube would be much larger than was envisaged, and expansion was necessary to meet these important requirements.

The major extensions under the expanded plan will be carried out at Corby. Steel capacity at this location will be increased to meet the new requirements in tube steel, and, in addition, a large tonnage of semi-finished steel in basic Bessemer quality will be produced. This semi-finished steel tonnage will be almost equal to that envisaged in the Green Field scheme in the East Midlands area, which was included in the report of the British Iron and Steel Federation to the Minister of Supply. By reason of the existing facilities at Corby, it will be possible to instal this capacity in a much shorter period of time, particularly since a great deal of development work would require to be done in connection with the East Midland location. For this reason, the Corby expansion will probably take the place of the Green Field scheme within the National plan in the meantime.

In general terms it can be said, that the proposals involve nearly doubling the Company's pre-war tube capacity and more than doubling its steel capacity.

The United Steel Companies, Ltd.—This firm is responsible for about one-tenth of the £168 millions expenditure of the Development Plan. Most of it will be spent at the Appleby-Frodingham branch, and the rest at the Steel, Peech and Tozer, and Samuel Fox & Co., Ltd. branches in Sheffield, and at Workington.

Appleby-Frodingham Steel Company.—The Frodingham melting shop has already been replaced by the new South melting shop with two open hearth furnaces of 300-tons capacity, electrically tilted and with electrically operated doors and reversing gears. One of them recently set up a European output record by producing 3,148 tons of ingots in one week. About 75% of hot metal is used and 25% works scrap. There is also a 600-ton mixer. Hot metal is provided by the Company's two most modern blast furnaces, which were blown in during 1939 and are adjacent to the new melting shop. It is eventually intended to provide a

further two blast furnaces with 27 ft hearths. Meanwhile the output of the existing furnaces is being improved by installing improved preparation plant and a sintering plant of unique design. The existing battery of 66 Koppers coke-ovens and the by-product plant is being doubled.

The section rolling mills are being reconstructed and electrified. A new 42-in. cogging mill has been installed. The existing 32-in. roughing and finishing mills will be moved into new positions. The new layout is designed to maintain output from the cogging mill at between 5,000 and 5,500 tons per week and from the 32 in. mill at between 3,500 and 4,000 tons per week.

Large central engineering workshops are also being provided and it is hoped that these will be completed in 1948.

Steel, Peech and Tozer.—The modernisation plans at this branch of United Steel Companies began in 1944 with the installation of a new cogging mill. This mill has already rolled up to 16,000 tons per week and is believed to have the highest output capacity in the country. It has made possible an increase in production of the order of 15 to 20%.

In the melting shops 8 out of 21 open hearth furnaces have been converted to oil-firing, and two more are at the present being changed over to base tar, which is a domestic product. This should result in an increase in ingot production of about 10%.

As the melting furnace re-building programme permits 18 waste heat boilers will be installed, the effect of which will be to eliminate practically all the coal-fired boilers on the works. The ultimate saving of coal which the waste heat boilers will effect is expected to be 50,000 tons per year.

The wheel and tyre mills are being entirely re-built. So far an ingot breaker has been installed which has speeded up and reduced the cost of preparation of the blocks. A bogie type furnace and other coke-oven gas-fired furnaces are now in commission. A 6,000 ton press, hydro-pneumatically operated, and a new mill, electrically driven, have recently been completed. The heat treatment plant has been entirely modernised. Additional equipment is still being installed and it is estimated that production will be increased by at least 30%.

Improvements, including mechanisation as far as is practicable, have been made in the manufacture of railway laminated springs, and a scheme of electrification and improvements of the small bar and section mills is in hand.

All these developments have necessitated an improved water supply system estimated to cost £150,000, which will comprise a new filtration plant and a new twin-pump house capable of taking 12 million gallons per day from the river Don.

Other developments associated with the scheme are the engineering workshops which are being re-built on modern lines so that plant maintenance can be carried out efficiently. Wherever possible all buildings are being enlarged to enable greater outputs of finished products to be handled expeditiously. Both the rivers Don and Rother are being diverted to improve the general layout and enable the Railways to deal with an increased volume of traffic.

The Workington Iron and Steel Company. As part of the United Steel Companies' rationalisation plans, the manufacture of rail steel, sleepers and other railway

material was concentrated some years ago at the works of this branch, where the type of steel produced makes it especially suitable for rail steel. It will be recalled that the White Paper on the Industry, in selecting the Workington Iron and Steel Company as one of the four principal rail makers in the United Kingdom, endorsed this choice. It is against this background that this Company's present and long-term modernisation programme must be judged.

During the past 15 years, the United Steel Companies Limited have incurred capital and revenue expenditure amounting to £3½ million on improvements. Outstanding schemes amount to a further £1½ million. The modernisation schemes already completed fall under four broad headings:—

(1) *The raw material departments*, including the development of a new iron ore field south of Egremont, an ore stockyard, ore crushing, screening and sintering plants, limestone quarries and ancillary preparation plant, and a new battery of coke-ovens complete with by-product plant.

(2) *The blast furnace plant*, including the concentration, mechanisation, and re-building of the Derwent blast furnace plant, together with ancillary plant such as gas-cleaning, pig casting, slag and iron disposal.

(3) *Steelworks*. The replacement of the former acid Bessemer steel-making plant by an entirely new plant of larger capacity, the installation of a 20-ton electric arc furnace, and modifications to the rolling mills.

(4) *Improvement and modernisation of ancillary plant*, including services such as steam, electric power and general maintenance shops.

The principal reorganisation schemes, which are now nearing completion, can be conveniently summarised as follows:—

(a) *The installation of a new cogging mill* with electric drive and a capacity of not less than 8,000 tons of ingots per week.

(b) *The extension and modernisation of the rail-finishing banks*, which will incorporate roller-straightening and special finishing machines.

(c) *Two additional boilers* (each unit having a capacity of 100,000-lb. of steam per hour at 420-lb. pressure) are being installed, which, on completion, will render the whole works independent of supplies of raw coal for steam-raising.

(d) To utilise the extra steam available, the capacity of the *Electric Generating Station* is being increased. Besides meeting all internal electric power requirements, surplus electric power will be available for disposal elsewhere.

(e) A 3,000,000 cubic feet capacity coke-oven gasholder will be completed by the autumn of this year.

By 1950, it can be said that in all major respects the plant and equipment of the Workington Iron and Steel Company will have been entirely renewed and modernised.

Samuel Fox and Company Limited. Well over £1 million will have been spent on plant improvements and developments at Samuel Fox and Company, Limited, since the end of the war. At the Siemens' melting shop it is the intention to instal four waste-heat boilers and one of these has already been installed. Three of the open hearth furnaces have been converted to oil firing. To ease the traffic situation, lime and dolomite storage bunkers have been installed and a new overhead crane enables materials to be more rapidly

handled to and from the stage. The billet mill has been equipped with an additional Priest continuous soaker furnace with a throughput of 15 tons per hour. An additional Thompson water tube boiler has recently been installed and another is projected. These boilers consume only low grade fuel, 75% of which comes from the coal washery and the other 25% is slack.

In the stainless sheet department the furnace capacity is being increased by 25% and a number of additional polishing machines including a battery of 12 ft. × 6 ft. Craven polishers and a Mattison machine have been installed. At the lower end of the works, a new gas holder will soon be completed for storing the gas which comes direct from the Orgreave coke-ovens, a distance of just over 14 miles.

The cold-rolled strip heat-treatment plant consists at present of 22 G.E.C. pit-type electric furnaces for bright annealing. The first of these was installed at the beginning of the war, but the majority have been installed since 1945 and it is planned to add five more. The manufacture of clock spring material and precision strip is being extended. New plant recently fitted includes two Robertson 4-high reversing high-speed mills capable of operating at 1,000 to 1,500 ft. per minute.

An interesting installation is the six hardening and tempering units now in operation for the treatment of clock and main spring material. These units produce about one ton a week and are designed for extremely accurate control of temperature. This department is rapidly expanding and will shortly have 12 units in operation, and with this capacity it is thought that all such strip formerly imported will be produced in this country.

The wire department in general is being reorganised and a number of new machines have been installed. The laminated spring plant as converted ten years ago to fully mechanical continuous line production, incorporating the latest developments of that time. A further reorganisation scheme is now in hand involving the installation of new plant including forced air circulation furnaces, highly specialised machine tools for machining the spring leaves, shot-peening, aluminium sprays, etc.

Apart from these developments at the Stocksbridge Works, Samuel Fox and Company, have other schemes in the small Sheffield works they acquired from Messrs. Darwins, Limited in 1945. This works is adjacent to United Strip and Bar Mills (part of the Steel, Peech and Tozer branch) from which it obtains its raw materials. It has an output of about 160 tons per week of strip and a small tonnage of fine wire.

Research Activities

During the period under review the research activities of the industry have progressed in unison with other developments. It is true that a central research organisation for the industry was only set up in 1945, but the background of research in the industry is quite extensive. Research in this industry was initially organised on a national scale in 1917, when five research committees were set up. Six years later a further effort was made to establish co-operative research on a wider basis by the formation of further committees. Two years later the Iron and Steel Industrial Research Council was formed which was responsible for much valuable work in raising the standard of attainment in the industry. Thus, when the British Iron and Steel Research Association was formed in 1945, it took over a

live organisation, and it has now become the largest industrial research organisation in the country.

It will be appreciated that nearly all steel works have well-equipped and well-staffed research laboratories, some of which are of an outstanding character, but much supplementary work is carried out on a co-operative basis, a considerable part of which is of a background nature and a central organisation functions to meet the need for co-operative research. The British Iron and Steel Research Association is organised in six largely autonomous divisions, corresponding to the six main divisions of the industry, viz: iron-making, steel-making, mechanical working, steel castings, plant engineering and metallurgy. There are three separate departments, physics, chemistry and engineering, which carry out work of a more fundamental character, and work common to a number of divisions. These departments also perform the incidental function of maintaining liaison between the divisions. The work of each division is controlled by a panel and each panel appoints committees to cover the various sections of its work. Altogether, over 50 committees control this Association's work.

The Iron and Steel Board

Just as there has been progressive development in the organisation on the production side of the industry, it will be noted there has been progressive development in control not only in organising supplies but in the prices consumers must pay for the semi-finished products of the industry. It will be remembered that a form of control on prices was emphasised in 1932 and during the more recent war they were fixed by the Ministry of Supply. Control of supplies and prices by this Ministry continued after the war until 1946 when the Government set up an Iron and Steel Board. This public Board includes representatives of the Treasury, steel consumers, management and the iron and steel trades unions and is responsible to the Ministry of Supply for prices, production, and future development in the industry.

For some considerable time, therefore, and especially since the establishment of the Iron and Steel Board, the control of general policy has been in the hands of the Government while the benefits of private enterprise and initiative have been maintained. The setting up of the Board was regarded by many as an experiment, but its establishment was welcomed by the iron and steel industry and generally the relations between the Board and the various iron and steel producing firms have been cordial and helpful, which have resulted in full co-operation and been of great benefit to the nation and the industry as a whole.

There can be no doubt that the present structure of the industry, which has established a balance between the centralised determination of policy and de-centralised responsibility of managements, has given good results in forward planning, in price control, and in high levels of production. So successful has this structure proved in the past two years that it would be desirable and practicable to devise proposals on a permanent basis, which, while maintaining the benefits of private enterprise and initiative so strikingly displayed in the industry, would give the Government effective control of general policy, a general control warranted by the particular relationship of the industry to the national economy both in war and peace.

Public Control v. Public Ownership

In the early months of the present Government it was proposed to introduce a Bill in Parliament to transfer to public ownership sections of the industry. Later, wiser counsels prevailed because of the urgent need to secure undivided concentration on increasing output and in carrying through the industry's development plan. During the last few months, however, there have been indications that the Government is reverting to the subject and proposes to introduce a Bill in the next session of Parliament, yet the need for concentration of effort in the industry has not abated. Responsible authorities have criticised the industry on its efforts, when only a few months previously the Government had publicly expressed its appreciation of the work done. It has been claimed that shortage of steel has caused a reduction in the targets set in some of the steel-consuming industries, but surely the cause of this is not due to lack of effort on the part of the iron and steel industry. To meet the targets of the steel-consuming industries, the steel industry, too, was set a target and, so far production levels are in excess of that target. Indeed, the production already achieved and the steady progress made with the industry's development plan show that through the Iron and Steel Board the Government and the Industry can achieve what is required.

This trend towards public ownership of vital industries is controversial from an economic as well as a political point of view; fundamentally, the issue is how far and in what respects shall the state intervene in the conduct of industry by private enterprise. So far transport and power have been nationalised. All are, so far, in their experimental stages and only the more optimistic would agree that they have proved successful. The change is much too recent to enable such a conclusion to be reached, indeed, it is probable that their establishment on a satisfactory basis may not be possible within ten years, thus, any further development of the policy of nationalisation should be very carefully studied in relation to the nation's economy and the peculiar characteristics of the industry it is proposed to incorporate.

The complexity of the iron and steel industry in particular, makes any movement towards complete nationalisation of this industry very difficult indeed, quite apart from any advantages or disadvantages such a system would have. Consider the main sections, which in addition to pig iron include steel; steel sheets; tinplates; hot-finished tubes; wire and wire rods; heavy forgings and railway tyres, axles, solid wheels and disc wheel centres; alloy and stainless steels; crucible and high-speed steel; light rolled sheet products and bolts, nuts, screws and rivets. Even these departments of the industry comprise some 500 firms. But these do not exhaust the number of trades making iron and steel products which can be classified as crude or semi-finished steel. In effect, the industry spreads out fanwise as it proceeds from the crude to the finishing ends, and the processes are so interwoven that a single firm may operate every one, including coke-ovens, blast furnaces, steel furnaces and rolling mills and other plant for the production of sheets, joists, rails, sections of all kinds, merchant bars and rods, etc. Larger firms extend further—to structural work and bridge building for example. Thus, the British iron and steel industry is, to a large extent, integrated vertically and, drawing a line of demarcation between that part con-

cerned with steel production and other parts that are primarily concerned with engineering, would seem to be impossible.

After careful consideration it would seem unwise to change a policy which is giving such admirable results, after relatively short trial, for a system of complete nationalisation which might seriously interfere with the whole production programme. The possibilities of success of such a

system can only be conjectured, whereas with the present policy of public control there is the assurance that the industry is achieving the targets set. Let us profit from the progress so far achieved and permit the iron and steel industry to use its imagination, foresight, genius, and vigorous action in overcoming its problems, to continue its good work in producing quality steel in increasing quantities.

Increasing Pig Iron Production

Trends in Manufacture and Plant

The increasing output of steel necessitates a corresponding increase in the production of pig iron. The present article includes a review of trends in pig iron manufacture in Britain, based on a paper by Colclough and Scott-Maxwell, together with a description of a recent installation at Colvilles' Clyde Iron Works.*

IT is estimated that, in order to satisfy the requirements of the present programme for increased production of steel and of iron castings, Britain's pig iron and ferro-alloy production will have to be raised to 11.4 million tons per annum within the next five years. This, with normal allowances for operation, represents a required capacity of 13 million tons per annum.

During the period 1921-1932, due to unsettled economic conditions, coupled with increased imports and the use of obsolete furnaces, the annual production averaged 5.5 million tons. Following the introduction of a protective tariff in 1933, extensive reorganisation was undertaken and production rose to a maximum of 8.5 million tons in 1938, a figure which was still half a million tons below the average for the twelve years prior to 1920. The need to use the lower quality British ores during the war led to a fall in output, the average annual production for the years 1939-1946 being 7.5 million tons. It will be seen, therefore, that to raise output to the required level is no small task. The contemplated expansion will be largely in furnaces making basic iron for steelmaking, although an increase of a million tons over the 1938 figure for foundry iron is envisaged.

The advantages of integrated plants are now fully realised and it is intended that almost the whole of the basic iron should be made in such plants. It is also likely that the production of foundry iron will be concentrated in four or five large units, with furnaces of 18-22 ft. hearth diameter. These plants will be integrated with coke ovens and foundries for the local use of a large part of the iron made, the gas from the coke ovens and blast furnaces being utilised in the associated foundries and chemical works. It is interesting to note in this connection, that Morrogh and Grant, in their paper on nodular cast irons, point out that metal direct from the blast furnace is often of suitable composition for cerium treatment.

Although there is a general trend towards increased output per furnace, as shown by the fact that the average weekly production, per furnace in blast, has risen from 1,110 tons in 1933 to 1,500 tons in 1946, the figure is still too low. In deciding on the size of furnace, however, it is necessary to consider it in relation to the steel plant with which it is integrated. It would be useless, for example, to have a single furnace supplying the entire needs of the steel plant, as the latter



View of No. 3 furnace showing the storage bins and winch house with Nos. 1 and 2 furnaces in the background.

would be left high and dry when the blast furnace was blown out. Nevertheless, it is accepted that the modern efficient unit should have a hearth diameter of 23-27 ft. and an effective volume of 40,000 cu. ft. with an output of 1,000 tons/day on rich-ore burdens and of 500-600 tons/day on home-ore burdens. In 1946, only 15 furnaces had hearth diameters over 18 ft., whilst 89 were below 14 ft. in hearth diameter. These small furnaces will have to be replaced and it is planned to build 24 new furnaces of over 20 ft. hearth diameter within five to seven years.

Operating Conditions

Optimum results can only be attained with these large furnaces by regular operation. The two main factors are the uniformity of composition of the ore and the uniformity of permeability to gases across the section of the furnace. Foreign ores are usually of

* *Jour. I.S.I.* June, 1948, pp. 186-192.

reasonably constant composition, but with British ores it will be necessary to operate a bedding plant.

With regard to the second point, the size of the ore and coke and the permeability of the ore govern the uniformity of the resistance to gas flow. Wide variation in size, with the present bell and hopper method of charging, results in a central core and outer ring of large pieces and an intermediate annular zone of closely packed small pieces with greater resistance to gas flow. The result is that most of the gases pass up the central zone and, to a lesser extent, the outer ring at such high velocities that there is not sufficient time of contact with the descending charge for its effective heating and reduction. In addition, much of the finer sizes of ore reaches the bosh in a relatively unheated and unreduced state. It has been shown that there is minimum separation of sizes when the ratio of maximum to minimum size of piece is 2 to 1. With British ores, therefore, the fines should be screened out and sintered and the remainder separated into two groups, in each of which the size ratio is 2 to 1. These two groups should be charged separately, in layers, so as to obtain maximum uniformity of permeability. With foreign ores the problem is complicated by the variation in permeability from one ore to another. For maximum output and minimum coke consumption ores of one or, at the most, two types should be used.

The work of Saunders, at the Imperial College, has resulted in a compensating charging device, by which it is hoped that the operator will be able to exercise a measure of control of the radial distribution of stock at the stockline. A suitable design for full scale operation has not yet been developed.

The average iron content of British ores mined in 1946 was only 29% and with rising fuel costs it is imperative that consideration should be given to the problem of upgrading the home-produced ores.

The quality of coke giving the best results is, to some extent, dependent on the characteristics of the burden, and it is significant that the best coke consumption figures are obtained in plants where the manufacture of the coke is under the control of the ironmaker.

Comparison of the rates of coke consumption in British and American practice, suggests that, given correct conditions, British furnaces could be driven at some 30% higher rate. In American practice, the limiting factor appears to be the loss of ore as flue dust and to overcome this inefficiency the tendency has been to increase the furnace height. With uniform distribution of materials this would probably be unnecessary. It is now suggested that flue dust losses could be reduced by creating a back pressure on the gas exit from the furnace, thus reducing the gas outlet velocity. The modification of the furnace and its ancillaries involves a number of engineering problems and considerable capital expenditure. In America, where the ores contain a large proportion of fines, the removal and sintering of the fines would also present a problem of considerable magnitude owing to the large tonnage involved, and it may be that the high-top-pressure method would be an economical proposition. In Britain, on the other hand, where the problem is one of dealing with ore which is too large for the furnace, crushing, screening and sintering must be resorted to in any case.

The use of oxygen enriched blast, as a means of improving production and reducing coke consumption, will be determined, in some degree, by the cost of oxygen.

The extent to which oxygen enriched blast can be used is limited by the fact that with oxygen above about 25% there is too little heat available for preheating in the stack, due to the greater absorption of heat in the bosh zone and the decreased volume of gases formed. This means that solid coke must be consumed in the hearth for heating and reduction of ore. Work is urgently needed, especially on full size modern units, to determine the point at which this balance is reached.

NEW PLANT

Having reviewed some of the problems involved in the proposals to increase pig-iron production in Britain it is opportune to describe one of Britain's latest furnaces, the No. 3 furnace at Messrs. Colvilles' Clyde Iron Works which along with the adjacent Clydebridge Steelworks forms the only integrated plant in Scotland.

Generally speaking, Scottish steelworks operate cold pig and scrap charges, largely as a result of the limited native ore deposits and the presence, in the area, of large consuming industries like shipbuilding and engineering from which a large amount of scrap can be obtained. In 1931, Messrs. Colvilles, Ltd. acquired the Clyde Iron Works with a view to operating the hot-metal process at their Clydebridge Works, situated on the opposite bank of the Clyde, the surplus metal being supplied to their other steelworks for cold charging.

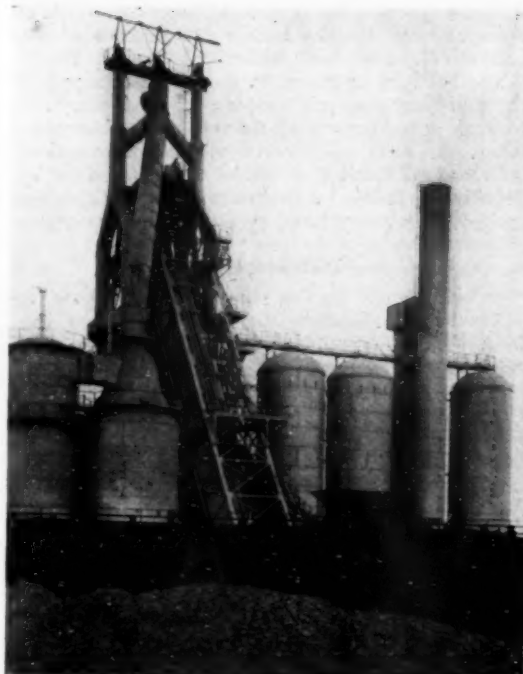
Dating back to the Napoleonic Wars, Clyde Iron Works was early in the forefront of progress. It was there that James Neilson, in 1828, first operated the hot-blast process and reduced the coal consumption, per ton of iron, from 8 to 5.5 tons.

To-day, the Iron Works consists of three blast furnaces, together with coke-oven and by-product recovery plants. The coke-oven and blast-furnace gases are used for steam raising, coke-oven firing and steel melting, whilst the blast-furnace gas is, of course, also used for heating the Cowper stoves. For buffering the gas supplies there are two gasholders, one of 1 million cu. ft. capacity for coke-oven gas and the other of 3 million cu. ft. capacity for blast-furnace gas. Of the three blast furnaces, two have already made over 1½ million tons of iron each, at a weekly rate of about 3,600 tons whilst No. 3 furnace was only blown in at the beginning of this year. This furnace will be dealt with in greater detail after a brief description of the associated plant.

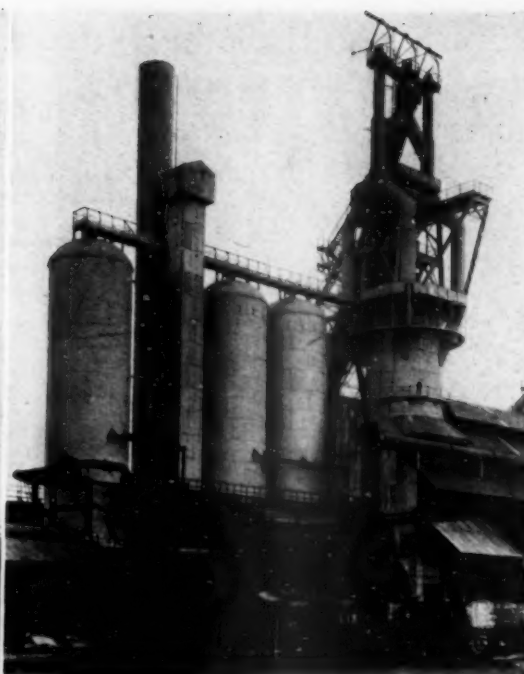
Coke-oven Plant

The battery of 68 Becker compound regenerative ovens is a Woodall Duckham installation, half being fired by coke-oven gas and the other half by blast-furnace gas. Each oven is charged with about 16 tons of wet coal, the coking time being a little over 18 hours and the weekly output of the plant 7,000 tons including nuts and breeze. After quenching, the coke, which is of low sulphur content and has good physical characteristics, is screened over 1½ in. mesh and transported to the storage bins by conveyor belt.

The blending plant consists of eight bunkers, each holding a particular grade of coal and fed from the wagon tipplers by a conveyor belt. Blending is achieved by regulating the amount of each type of coal fed to the crusher by a conveyor belt running beneath the bunkers. Before the crusher is reached the belt passes under a powerful electro-magnet which removes any pieces of steel which might damage the Stellite-tipped crusher hammers. The coal, after crushing to 80% less than



View of No. 3 furnace from the charging side.



Front view of No. 3 furnace.

$\frac{1}{8}$ in., is fed into the large storage bunker from which the oven charging hoppers are loaded.

The coke-oven gas, after passing through a semi-direct by-product plant, in which benzole, toluol, xylol, sulphate of ammonia, naphthalene and crude tar are recovered, is used for the various purposes outlined above.

The present coke-oven plant is not capable of supplying all the needs of the blast-furnace plant, and a scheme has been approved for the erection of a further battery of 67 ovens, which will make the plant independent of outside supplies of coke. This is much to be desired from the point of view of regularity of operation of the furnace.

Raw Material Storage

The wagons in which the ore and limestone arrive are emptied by tipplers and the contents delivered to the crushing plant. After crushing, the fines are removed by screening, and sintered along with the flue dust from the furnace. The products of the screening and sintering plants may be fed direct to the storage bins or handled in a large stockyard situated behind the bins and serviced by an ore bridge crane.

The storage facilities of the whole plant comprise 24 bins, each of 350 tons capacity, for ore, sinter, limestone, etc., together with six coke bins (two for each furnace) of 130 tons capacity.

Power Plant and Blowers

The present power plant consists of two 5,000 k.v.a. alternators generating at 11,000 volts, two 230/240 volt, 0-2,500 amp. rotary converters and one 1,000 k.w. d.c. generator. A further 5,000 k.v.a. alternator will shortly be going into commission.

Each furnace is blown by a 4,500 b.h.p. Metropolitan Vickers turbo-blower, rated at 45,000 cu. ft./min.

at 25 lb. gauge. This rating is higher than actually required, but the design is such that a wide range of operating conditions is possible. Normally the blowers operate at constant volume and are governed by an "Askania" regulator. By means of a manifold and valve gear, interchange of blowers can be effected. In addition to the three main blowers, there is a 1,730 b.h.p. blower rated at 30,000 cu. ft./min. at 10 lb. gauge.

Steam for the blower turbines is raised in a bank of Stirling boilers fired by blast-furnace gas, coke-oven gas or, in case of emergency, oil. Blast-furnace gas-fired Babcock and Wilcox boilers supply the steam for power generation.

No. 3 Blast Furnace

This latest addition to the plant was built by Messrs. Ashmore, Benson, Pease and Co., Ltd., and is one of the largest in Britain, the hearth diameter being 20 ft. with a 23 ft. bosh, and the height, from tap-hole to deck ring, 91 ft.

Six fabricated steel columns support the stack, which is of riveted construction. The lining is entirely of firebrick, "Stein Nettle" quality bricks being used for the hearth, tuyere zone and bosh whilst the stack is lined with "Stein Glasgow" bricks. Wear of the brickwork at the throat is prevented by two rows of mild steel plates 9 in. deep, and four rows 12 in. deep, built into the brickwork and turned down parallel with the lines of the furnace.

At the hearth, cooling is effected by means of segmental cast-iron stove coolers. Water cooling is extensively applied to the lower part of the furnace. Ten rows of 24 flat copper coolers per row, and one row of 12 flat coolers are used for the tuyere and bosh zone,



View of the lower part of the furnace taken from inside the cast house.

whilst the lower part of the stack is cooled by eight rows of flat coolers with 16 coolers per row.

Air is blown into the furnace through 12 tuyeres and the gas is taken off by four vertical brick-lined uptakes, which unite first in pairs and then into a single downcomer as will be seen in the photographs. Baer bleeder valves are fitted at the top of each pair of uptakes as well as at the top of the downcomer. From the downcomer the gas passes first through a Zimmerman type dust catcher and then through a "Vortex" dust catcher, both provided with dust conditioners, and so into the crude gas main via a thermal expansion goggle valve. Before use, all gas is further cleaned, in Whessoe disintegrators, to better than 0.02 gms./cu. m., the normal figure being 0.012 gms./cu. m.

Charging Equipment

Ore, sinter and flux are weighed into an electrically driven Atlas scale car which has a 150 cu. ft. capacity hopper and is capable of weighing to 20,000 lb. The coke is delivered from the storage bins to twin automatic coke weigh-hoppers by twin belts which pass the coke over a static debreezing screen in the process. The weigh hoppers are situated immediately behind the skip pit so that each can fill one of the skips.

The skip hoist, supported independently of the furnace top, has two skip cars, each of 130 cu. ft. capacity. The skips are hoisted, by a 200 h.p. electric winch, at a maximum speed of 316 ft./min. At the furnace top, the skips are discharged into a standard McKee distributor. Skip winding, distributor operation and bell dumping are all automatic and sequence controlled, so

that the operator has only to fill the skips in the correct order and operate the master switch situated conveniently to the scale car platform at the skip pit.

The bells are operated by air cylinders supplied from the cold-blast main, the motorised valves being arranged to work in sequence with the rest of the charging equipment. In case of emergency, the air cylinders may be supplied from the Works compressed-air system. The furnace is fitted with an automatic stockline recorder and an emergency hand-operated stockline rod.

Hot-blast Stoves

In addition to two existing hot-blast stoves, each of 113,000 sq. ft. heating surface, a new stove has been built with a heating surface of 133,000 sq. ft. The two original stoves have zoned checkers, the first zone being of "Stein Nettle" brick and the second of "Stein Glasgow" brick. The new stove is filled with zoned Foster Hotspur vaned checkers. All the stoves are fitted with 800 mm. Brassert burners with constant air/gas ratio control. The hot-blast valves are of Mathesius design, with water-cooled steel seats and water-cooled bronze paddles. Each stove has two Freyn chimney valves, two rack and pinion cold-blast valves and one 16-in. Freyn blow-off valve. Dome temperature pyrometers and flue gas sampling equipment are also fitted, whilst the hot-blast temperature is controlled by Foster constant temperature equipment. This is a balanced bridge type of instrument which operates a motorised valve to regulate the amount of cold air admitted to the stream of hot air leaving the stove. The hot-blast temperature is 650°-750° C. and its pressure 15 lb. gauge. There is a double beat snort valve in the cold-blast main with duplex controls in the furnace instrumentation house and on the other side of the cast floor.

Cast House and Instrumentation

The cast house which, as will be seen from the accompanying illustration, is covered in, is served by a 10-ton overhead crane which is shared between Nos. 2 and 3 furnaces. The tap-hole is opened by a rotary drill, driven by compressed air, and an oxygen lance. Closure of the tap-hole is effected by an electric chain driven clay gun of Ashmore, Benson, Pease design. The runner is of cast iron and is fitted with a permanent dam and a Killeen skimmer. Provision is made for five 70-ton enclosed-type metal ladles to be accommodated on two parallel tracks, so that Nos. 2 and 3 furnaces can be tapped simultaneously if necessary. In the present programme No. 3 is tapped five times a day.

The furnace control house, conveniently situated in a corner of the cast house so that a full view of the tap hole, cast house floor and metal ladles is obtained, contains the gun controls, snort-valve control and "Ordasign" signalling equipment to the blower and a "Loudaphone" system communicating with the power station. The instruments housed include blast pressure and volume indicators and recorders, top-gas pressure and temperature indicators and recorders, a four-point stack temperature recorder, a stockline recorder and a combined stockline depth indicator and visualiser.

Conveniently grouped on the cast-house floor are the controls for the bleeder valves, a hand stockline rod, the steam valves for purging the dust catcher, the gas uptakes and the gas seal, and the steam and water valves for the goggle valve to the crude main.

Continued on page 152

Alloy Die Steels

By L. Sanderson

Dies for stampings, forgings and castings are subjected to heavy service conditions and to obtain economic production from them necessitate careful selection of the steels used in their manufacture and in their subsequent heat-treatment. The cost of a suitable die for a particular component may be considered high, but when this cost is spread over the number of components produced from it the cost will be low; good dies, which permit long runs, therefore, make for efficiency and economy in production. Steels for such and their treatment are discussed.

DIE steels can be divided into two main classifications, those for hot work, and those for cold work. As the cold working die steels are the more common in use, this section is concerned with the most representative examples of this type, beginning with the high-carbon, high-chromium non-distorting die steels.

DIE STEELS FOR COLD WORKING

Many ordinary die steels, though admirable for many purposes, are not capable of standing up to the severe service represented by long runs, or operation on particularly difficult materials. For this reason it has been necessary for steel manufacturers to produce special alloy tool steels containing relatively high percentages of expensive alloying elements. Such steels are inevitably higher in first cost, but are capable of performing highly exacting work, so that the difference between their cost and that of an ordinary die steel is often saved many times.

High-Carbon High-Chromium Steels

Steels of the high-carbon, high-chromium type can be used for blanking, tin-making, coining, cutting, drawing and thread-rolling dies. They can also be used for many other purposes with great success, e.g., plug and ring gauges, mandrels, press tools and bushes. Steels of this type need to be correctly heat-treated, and, if this is done, they will not be deformed or altered in volume, while their cutting edges will last considerably longer than those of the ordinary die steels. They can be used on both soft and hard materials.

There are many proprietary brands of these steels, all varying slightly in either method of manufacture, composition, heat-treatment, or other factors, but in the main they can be grouped into three main types indicated in Table I.

TABLE I.—MAIN TYPES OF HIGH-CARBON HIGH-CHROMIUM DIE STEELS.
TYPICAL COMPOSITIONS.

Carbon %	Chromium %	Vanadium %	Molybdenum %	Cobalt %
2.0-2.5	11.0-13.0	0.1-0	0.0-8	0.0-5
1.5	12.0	0.1-0	0.8	0.0-5
1.0-1.4	12.0	0.1-0	0.8-1.0 (max.)	3.5

In general, the first type of steel shown in the above table is hardened by quenching it in an oil bath. The other two steels may be hardened in either oil or still air. These two steels are somewhat tougher than the first, and can be more easily machined, but they are less suitable for the longest runs, and for those conditions in which a high degree of resistance to wear is required. They represent a compromise between the two requirements of resistance to wear and toughness. All three steels are, however, alike in being of non-distorting type,

with minimum volume change when correctly heat-treated, resistant to wear but rather brittle as compared to the ordinary die steels.

These steels, when set to work, sometimes break down in a curious way. They may have carried out extremely long runs, when all at once the cutting edges begin to snip off. This is caused by fatigue strains. When it happens, the user must re-soften the dies by an annealing operation, machine them again, and re-heat-treat. This is better practice than merely regrounding the snipped edges, which does not remove the fatigue strains. Dies so treated will give long service.

Grinding these steels is necessary, of course, when the edges have blunted, but is an expensive operation, owing to their great abrasion resistance. Care in the choice of grinding wheels is essential to prevent the formation of surface cracks, caused by the generation of excessive localised heat. It is advisable to employ a soft wheel of self-dressing type.

When fractured, these steels are found to have a structure closely akin to that of high-speed steel, and for this reason great care in forging them must be exercised. They must not be heated to too high a temperature, nor must they be brought to the forging temperature too quickly, as this results in an undesirable degree of brittleness. They should first be warmed slowly, then brought by degrees to a temperature of about 870° C., and the temperature then increased slowly to 1,000-1,100° C., the latter figure being an absolute maximum. The steel should be given time for the heat to penetrate right through the mass before forging begins, and only light blows should be given at the outset. The steel will cool as forging continues, and the moment a temperature of 950° C. is reached, forging must stop. Should there still be some forging work to be done, it is essential to re-heat the steel as often as may be necessary for completion. Too large a reduction of size must not be attempted at one blow.

When forging has ended, it is better to bury the steel in some non-conductive material such as ashes, lime or mica, so as to retard cooling, and thereby prevent internal stresses from occurring. Normalising (stress-relieving by re-heating and cooling in the air) is advantageous. The larger the mass of the piece being forged, the higher should be the forging temperature, as long as the permissible range is not exceeded. Such masses can then be given fairly heavy blows or quick reductions.

On the whole, these steels call for a longer heating period for forging than high-speed steels, though the forging temperatures will be somewhat lower by reason of the lower melting point of the high-carbon, high-chromium steels. Their relatively low thermal conductivity means that they take longer to heat up, while during

both heating and cooling they are liable, as a result, to considerable variation in temperature throughout the mass in all but the smallest sections. Hence, severe internal stresses will be caused, unless the warming or pre-heating recommended is adopted, and these stresses are quite capable of leading to failure.

The introduction of vanadium into their composition is optional. The greater the vanadium content within the limits given, the smaller becomes the forging temperature range.

Normalising is advisable, as stated, after forging, and is carried out by heating the steel to 850° C. before it has become quite cold, and then letting it cool in still air in a dry place. Some users argue that normalising is not necessary, and in the United States it is not always adopted, but as a result of long experience British metallurgists favour it.

To soften or anneal these steels so that machining can be done upon them, it is necessary to heat them in a suitable furnace to a temperature between 800 and 840° C., for a period ranging from two to four hours, after which the steel is left to cool gradually in the furnace.

The annealed material should show a Brinell hardness number of the order of 225-30. The steel should be enclosed in a sealed receptacle, which ensures gradual cooling, and either clean cast-iron chips, charcoal, or some natural substance, should be included so as to avoid the tendency of the steels to lose carbon from the surface when in the annealing furnace. Furnace cooling should not be faster than 25° C. per hour until a temperature in the region of 550° C. has been attained, but may then be speeded up, if necessary.

If for any reason an even softer steel is desired, slow cooling from 900 to 550° C. should be carried out, after which follows re-heating to 800° C. and gradual cooling. To harden the steel, the first essential is precautions against decarburisation of the surface, commonly known as *soft skin*. This involves heating the steel wherever possible in a modern type of atmosphere-controlled furnace, preferably with pyrometric control. It is often advisable to enclose the steel in a container together with a suitable carburising or neutral substance, as for annealing. Charcoal at the hardening temperature is inadvisable except in a few special instances because it is liable to give the die a glass-hard surface, which may not be good practice; spent pitch coke is preferable.

The steel should first be slowly pre-heated to a temperature within the range 750-800° C., heated to 1,020 to 1,040° C., and held at that temperature long enough for the heat to soak right through, then allowed to cool in air. The soaking or temperature maintenance period depends on the form and dimensions of the piece, but is approximately three times as long as that for carbon tool steel of equal mass.

When it is desired, or advisable, to harden the steel in oil, i.e., when maximum toughness is required at the expense of some hardness, the steel must be heated to 980° C. This lower temperature gives a smaller size of crystals or grains and therefore a stronger steel. Where greater hardness is required, the air-hardening method and temperature range should be adopted. The dies so hardened will be more heat-resistant.

The surface-hardening processes known as *nitriding* and *cyaniding* can also be applied to these steels, but when nitriding is to be carried out after hardening, the higher hardening temperatures should be employed.

Tempering is carried out by heating the steel to 200 to 250° C. and maintaining it at this temperature for a period of from two to three hours. Some qualities of this steel do not respond so well as others to this low-tempering temperature, being unduly brittle after the treatment. In these instances, and where the maximum toughness is required as a result of the design of the tool, the tempering temperature range can be raised to 400 to 450° C. and the temperature maintained for from two to three hours. It is essential that the steel should be heated gradually to these relatively high-tempering temperatures so as to avoid any risk of cracks.

The steels in which the carbon content is lower require on the whole higher quenching temperatures if they are to be given the greatest degree of hardness, but it is to be observed that the method of hardening in a sealed container produces the maximum hardness in the quenched condition when the hardening temperature does not exceed 980° C. If this temperature is exceeded, it is probably better to harden in oil for maximum hardness. If the steel is maintained for a considerable period at the hardening temperature, there is usually a decline in its ability to withstand impact shock.

Little volume change is experienced when these steels are hardened, and this is one of their greatest advantages when used for dies. In fact, the average overall modification in volume is smaller than for any other steel. On the other hand there is some tendency to elongate in the direction in which the steel was originally hot-worked. The higher hardening temperatures with some of these steels, particularly those of higher carbon, lower chromium type, have been known to set up a slight volume contraction.

If these steels have a drawback, it is that they are somewhat difficult to machine, because they are liable to adhere to the cutting tool and build up on the tool nose. The steels of lower carbon content are the more machineable. Vanadium to the extent of 1.0% (max.) is sometimes added to improve machineability.

High-Carbon Low-Alloy Steels

We now come to the non-distorting alloy steels for dies, designed primarily to harden in oil, a few representative types of which are given in Table II. These are less costly than the high-carbon, high-chromium die steels, but they are still relatively free from contraction, distortion, cracks, volume change, after the quenching treatment. Usually, they are not difficult to handle or treat, and their hardness when made up into dies is about Brinell No. 630 to 652, i.e., 62 to 63 Rockwell C, or Vickers Diamond 834. A steel of this type can be used for dies of somewhat complicated form wherever, for economic reasons a lower-priced steel than the high-carbon, high-chromium type must be adopted, or where the work to be done is not such as to compel the use of a better material. Where there is a danger of severe distortion or cracking in quenching, these steels must be used in preference to carbon tool steels. They are, however, rather more susceptible to movement and volume change than the die steels of high-chromium, high-carbon type.

Their grain structure is refined, and the hardness given by quenching penetrates fairly deeply so that when relatively small pieces, i.e., of small cross-sectional area, are hardened, they should have a hardness value of about Brinell No. 683, i.e., 65 Rockwell C. Larger pieces cannot be expected to give so high a value, however. A good average is 187-207 Brinell.

The steels are readily machineable. Table II gives a few representative compositions, but there are many proprietary brands, and the respective manufacturers should be asked to provide the compositions of their particular steels. In addition to dies, these steels can be used for stay and milling taps, delicate broaches, milling cutters, plugs, gauges, circular cutters, fine press tools, master tools, marking rolls, tobacco tin trimming cutters, blanking tools, chasers, punches, etc.

As oils quench steel less drastically than water or brine solutions, there is less danger that steels of these types, made into dies, will crack or shrink.

TABLE II.—SOME TYPICAL HIGH-CARBON LOW-ALLOY DIE STEELS.

Carbon %	Tungsten %	Chromium %	Vanadium %	Manganese %
1.0	0.5	0.8	—	0.9
0.9	0.5	0.5	0.2	1.1
0.9	—	—	—	1.6
1.15	1.6	0.5	0.2	0.5

To forge these steels, which are usually supplied in the annealed condition, gradual and even heating to 950 to 1,000° C. is required. The steel should preferably be warmed before it is introduced into the furnace, and too rapid a heating rate must be avoided. Otherwise cracks may arise. Forging must not be continued after the temperature has fallen to 700° C. Even heating to the forging temperature is, as stated, essential, and should be continued long enough for the steel to be heated right through. It is better to re-heat the material as many times as may be required to complete the forging operation rather than to risk forging at too low a temperature.

When the forging operation has been completed, strains will be left in the steel, and these must be removed by a normalising treatment comprising introduction of the forged piece, when quite black, into a furnace and heating it slowly to 820° C. The heating period should be from 15 to 60 mins.; the larger the mass, the shorter the heating period. It should be noted that the forging temperature given above is variable, within 50° C., according to the mass of the piece, being higher for large pieces and heavy or quick reductions and lower for the smaller parts and reductions.

To harden the steel, it is then heated slowly and evenly, giving adequate time for penetration of the heat. At a cherry-red heat, e.g., between 780 and 800° C., the steel is quenched in an oil bath. Pre-heating gradually and evenly to approximately 650° C. is advantageous because it lessens the risk of warping and produces the greatest possible and most uniform hardness. The third steel of Table II should be quenched the moment the heat has penetrated to the centre; the second and fourth steels tabulated should be allowed to remain at the quenching temperature rather longer, because this produces a higher degree of hardness at the risk of a little more distortion.

Complicated dies or other tools in which there are sharp alterations in cross-sectional area must not be brought to the quenching temperature quickly, or they may fracture or distort. The oil used for quenching should not be dead cold, but held at a temperature between 40 and 50° C. The steel should not be left in the oil bath until it is dead cold, but should be taken out before it has cooled to 100° C.

It is important that the quenching bath should not be allowed to attain too high a temperature, which is always possible if too many parts are hardened in it over

a prolonged period. This means not only that the tank should be large and deep enough to hold a good volume of oil, but also proportionate in volume to the amount of work to be handled. Notes on this point will be found in "The Heat-Treatment of Steel," by Gregory and Simons.*

The furnace in which the steel is heated to the hardening temperature should preferably be one in which the atmosphere can be controlled, and should be somewhat oxidising in character because this reduces the liability of the steel to decarburise, i.e., to surrender some of its carbon to the oxygen in the air, thus forming a soft skin.

The tempering operation should follow directly after the steel has cooled after quenching. The steel must be placed in a furnace and reheated to a temperature suitable to the purpose. A convenient working range is 200 to 250° C. Threading and stamping dies, stay taps and similar tools can be tempered a straw colour (230 to 250° C.). Cutting dies, punches, and drills, should be tempered to a dark straw. This renders them tougher and less brittle, and although a little hardness is lost, it is not of great consequence in these particular applications.

To prevent the dies from being of unequal hardness because the edges and corners have cooled more quickly, and are therefore harder, than the body, whereas the wide flat areas are protected from cooling by scale, it is a good plan to force copious supplies of oil against these areas under pressure.

To anneal the steel, it should be heated to 730° C. and allowed to cool gradually. It will not be possible to obtain a softness comparable to that of low-carbon steel (unalloyed), but if the treatment is properly carried out, the hardness attained should be in the region of Brinell 207, in which condition the steel presents no difficulty as regards machining.

When the steel is quenched within the temperature range 760 to 780° C. the shrinkage in length will be less than 0.001 inch per inch. Quenching at a temperature higher than this causes a small degree of expansion, not exceeding and usually less than 0.001 inch per inch. It will be appreciated that any lengthening of the steel causes it to become slightly thinner, and vice versa. In some instances the user may wish to give the steel an artificial ageing, so as to prevent the changes in volume occurring sometimes with steels after a lapse of time. This can be achieved by tempering the steel at 200° C., which will result in a movement within the limits given above, and so produce the artificial ageing required.

Carbon-Chromium-Molybdenum-Cobalt Steels

A steel for dies with a rather more limited application is marked by extremely high resistance to wear, combined with considerable hardness. It has a composition range of which the following is typical: Carbon, 1.0 to 1.5%; chromium, 12 to 13%; molybdenum, 1.5%; cobalt, 3.0%. In addition to certain types of dies, this steel can also be used for special cold sheer blades, cold press work, and heavy duty punches engaged on particularly difficult work.

The steel should be pre-heated, and then brought steadily and uniformly up to a temperature of 1,000 to 1,050° C. and forged at that temperature. It should be pre-heated for hardening to 750 to 780° C. and left long enough at this temperature for the heat to penetrate right through. Rapid heating to 1,020 to 1,050° C. follows, and this temperature range should on no account

* Published by Sir Isaac Pitman & Son, Ltd., London. Price 18/- net.

be exceeded. Quenching is carried out by means of a blast of air, so that this steel is what is known technically as an *air-hardening steel*. The tempering operation consists of heating to 200 to 250° C. and maintaining that temperature for about two to three hours.

Sometimes air-hardening is impracticable, and oil-hardening must then be adopted. In such circumstances the steel should be quenched at 980° C. and tempered at 200 to 250° C. If it is essential that the tools should be in the toughest, least brittle condition after heat-treatment, it is necessary to temper at 450 to 520° C. and maintain this temperature for from two to three hours. This is only required when the design of the tool makes toughness the primary consideration.

To anneal the material, it should be heated to 800 to 840° C.

DIE STEELS FOR HOT WORK

The next types of die steels are those for hot work and of these the first to be dealt with here has been specially developed for fatigue-resistance and because of its ability to retain its form and hardness at elevated temperatures. It is specially suitable for hot-working dies, used in the manufacture of rivets, nuts, bolts, hot brass stampings, die-casting dies, etc. It can also be used for hot punches and for the liners in the hot extrusion of intricate sections.

Tungsten-Chromium Steels

A typical composition range is as follows: carbon, 0.3 to 0.35%; tungsten, 10.0%; chromium, 3 to 4%; vanadium, 0.2 to 0.5% (optional). This is, of course, typical only, and proprietary steels of this type vary slightly in percentages. Such variations may modify slightly the typical heat-treatment given later. In any event, the conditions producing the most satisfactory results differ according to the place of use, and the temperatures have to be modified to come within the limits given in relation to the local circumstances. The steel manufacturer is usually glad to advise.

The correct forging temperature range is 1,100 to 1,150° C. Forging should not be carried on after the steel has cooled to 900° C. When the work is completed the steel should be buried in some non-conductive material, such as lime, ashes and mica, so as to ensure gradual cooling. The higher forging temperatures are used when the cross-sectional area of the piece is heavy and where the reductions are severe or swift. The lower temperatures are for the smaller work and for less severe reductions.

The steel should be pre-heated for hardening to 750 to 800° C. ensuring that this is done slowly and evenly. The steel is then introduced into the high-temperature furnace, or chamber, and brought slowly and evenly to the correct quenching temperature, which is governed by the purpose. Thus, nut-heading dies should be quenched at 1,150 to 1,180° C. in either oil or air, oil being preferable. Dies for pressure castings should be quenched at 1,020 to 1,050° C. in oil or air.

To temper the steel, it should be gradually heated to from 500 to 580° C. and maintained at this temperature for at least one hour per inch of cross-sectional area. Re-annealing can be carried out by heating to 800° C. and allowing to cool slowly in the furnace. The steel must be maintained at the annealing temperature long enough to ensure that the heat has soaked right through the mass. Steels of this type have been tried for die-casting dies for brass, with mixed results.

Die-casting Die Steels for High-melting Point Metals

We now come to a further number of steels capable, like the steel just mentioned, of being used for die-casting dies, but primarily for aluminium and its alloys and for other alloys of high melting point. These dies are liable to fail as a result of cracks that form on the surface. The surface layer of steel is alternately contracted and expanded until it reaches its *fatigue point*, i.e., the point at which it can no longer withstand the stresses imposed upon it. Moreover, corrosion and erosion attack this layer, and there is also a mechanical splitting action caused by the forcing of alloy fins into these cracks under pressure.

The moment a crack begins, the next batch of alloy in the die at once fills it with molten metal. This solidifies and stays behind in the crevice. Every time the die is used after this, the wedge of solid metal so formed is hammered further and further in, so that the crack becomes steadily deeper. Hence the need for steels that will not crack on the surface when subjected to severe temperature variation. The general tendency in modern die-casting plants is to use a steel of highly alloyed type. The precise composition of the steel is governed primarily by the length of the run, and by the working temperature. The steels of this type are summarised in Table III.

TABLE III.—TYPICAL DIE-CASTING DIE-STEELS FOR HIGH-MELTING ALLOYS.

Carbon %	Tungsten %	Chromium %	Vanadium %	Molybdenum %	Silicon %
0.3	5.0	5.0	—	0.5	1.0
0.3	—	5.0	0.25 (opt.)	1.0	0.9
0.3	1.0	5.0	0.25 (opt.)	1.0	0.9
0.5	—	2.0	0.2	—	—

The relatively high tungsten steel referred to in the table is usually received by the user in the form of annealed bars or blanks. To forge it he should heat the steel to within the temperature range 950 to 1,000° C. To harden it, he should pre-heat to 650 to 700° C., and allow sufficient time for the heat to soak right through the bar or piece. The temperature should then be raised quickly to 950° C. and quenching in oil or air should follow. The tempering treatment comprises heating the steel to 550 to 680° C. and maintaining it at this temperature for a period of from two to six hours. If it is desired to anneal the steel, this should be done at 800° C.

The low chromium steel of Table III should be forged at 950 to 1,000° C. and pre-heated to 650 to 700° C. for hardening. When this temperature is attained, the steel should be heated to 850° C. and kept at that temperature until the heat has penetrated right through. Oil quenching follows, and the steel is then tempered for a period of 90 minutes at 500 to 550° C. This steel can be annealed at 730° C.

When the two other steels referred to in Table III have been forged, at 1,100 to 1,150° C., they should be slowly cooled by burying them in lime, ashes, mica, or some other non-conductive material, so as to prevent cracks. Forging should on no account be carried on at a temperature below 900° C. After these steels have cooled, they should be annealed at 840 to 970° C. for a period of one hour per inch of cross section.

To harden these two steels, the first stage is gradual heating up to a temperature within the range 980 to 1,000° C. allowing a heating rate of 1½ hr. per inch of thickness and maintaining the temperature, when reached, for 1½ hr. per inch of cross section. The gradual

heating is designed to prevent distortion or volume change. Sometimes, when the die is complicated, an even slower heating rate than that given above may be required. Quenching of these two steels should be in still air, and tempering should follow on at once, at 540 to 600° C., which should give a Brinell of 402 to 460. The tempering furnace should already be at or about the tempering temperature before the dies are introduced into it, as otherwise the heating rate will be too swift, and the heating itself lacking in uniformity. A heating rate of about two hours or more per inch of maximum cross-section is recommended. Incidentally, before dies for aluminium die-casting are used, it is a good plan to heat them gradually and evenly to about 180° C.

Die-casting Die Steels for Low-melting Point Metals

The next hot-die steels to be dealt with are those designed for use on zinc and tin-base alloys. The temperatures at which these alloys are die-cast are comparatively low, and therefore highly alloyed steels are not required. The alloy steels mainly used other than those earlier mentioned are given in Table IV.

TABLE IV.—TYPICAL DIE-CASTING DIE STEELS FOR LOW MELTING ALLOYS.

Carbon %	Silicon %	Aluminium %	Chromium %	Vanadium %	Manganese %	Nickel %
0.5	—	—	0.9	—	0.8	1.25
0.45	—	—	0.8	—	0.7	—
0.2	—	1.2	1.2	Molybdenum 0.5 (max.)	0.5	—
0.45	0.9	—	2.25	Vanadium 0.2 (opt.)	0.6	—

The third of these steels must be subjected to a nitriding treatment for the best results. All the first three can, in addition, be used for lead base die-casting alloys. The fourth is specially suitable for long runs on zinc base alloys, and when forged, should be cooled slowly in the manner already described. As the treatments of these four steels vary, they have been tabulated in Table V. All, however, should be heated slowly to 790° C. before forging temperatures are attempted.

TABLE V.—TYPICAL HEAT-TREATMENTS FOR STEEL TABULATED IN TABLE IV.

Forging, ° C.		Normalise for 1 hr. per in. when necessary at ° C.		Anneal ° C.
Begin	Stop			
Heavy Sections	Light Sections			
1,040	1,100	840	900 for 20% of heating time	770-790 for 1-4 hr.
1,000	1,070	840	870 " " "	760-790 "
1,040	1,150	870	" " "	" " "
1,040	1,150	870	930 " " "	770-800 for 20% of heating time.

The third steel of these four is not usually annealed. Instead it is quenched in an oil bath from a temperature of approximately 950° C. and tempered at 680-730° C. to give a Brinell number of about 200 to 250. After any steel has been annealed, it should not be allowed to cool at a faster rate than 25° C. per hour until it has reached 540° C.

CONTINUATION OF TABLE V.

Heat for	Harden at ° C.	Quenching	Temper at ° C.
1½ hr. per inch thickness	820 to 840 Hold for 1 hr. per inch	In oil	260 to 43
—	870 to 900 " "	In oil	430 to 480

The first steel is not usually heat-treated unless it is to be used on zinc-base alloys. The third steel is given the normal nitriding treatment.* If the dies have been oil-hardened, they should be removed from the bath before they have become quite cold. Tempering of steels two and four should give a Brinell number between 402 and 460. Tempering should be continued for a period of two hours per inch of cross section.

If steel No. 4 is used for complicated dies, it is advisable to hold it at the hardening temperature for the entire period indicated, and then allow the temperature of both furnace and work to fall to 820° C., which temperature should be held long enough for the die to be thoroughly permeated. The die should then be hardened in the oil bath.

Die-casting Die Steels for Copper Alloys

Steels for die-casting dies for brass and the copper alloys have been the subject of considerable experiment, and it cannot be said that finality has yet been reached. In the United States a steel containing 0.35% carbon, 10.0% tungsten, 3% chromium and 0.5% vanadium has been used. Such a steel should be heated slowly to 840° C., then brought quickly to 1,120° C. for heavy sections and 1,180° C. for light sections. Forging is then begun, but must not be carried on when the steel has cooled to 900° C. Next, an annealing treatment should be given, the steel being heated for from one to four hours at the rate of one hour per inch of cross section to a temperature within the range 870 to 900° C.

After a pre-heating to 820 to 840° C. the steel is brought rapidly to the hardening temperature, which is between 1,000 and 1,180° C. There is no heat maintenance period, quenching in air or oil following at once. Tempering is at 540 to 680° C.

Some of the die steels can be used for either hot or cold work. A 2% tungsten, chromium, vanadium steel is of this type. When it is used for cold dies, it must be tempered at 200 to 230° C. For hot dies, it must be tempered at 500 to 550° C.

MISCELLANEOUS COLD-WORKING DIE STEELS

Although strictly they should be included among the cold die steels earlier mentioned we have left to the last a number of miscellaneous cold-working die steels. First, there are the cold-heading die steels. Of these there are only three of real significance: they are all of high-carbon type, and typical compositions are shown in Table VI.

TABLE VI.—TYPICAL COMPOSITIONS OF SOME COLD-WORKING DIE STEELS.

Carbon %	Manganese %	Chromium	Vanadium %
0.9	0.3	0.3 (max.)	0.5 (max.)
1.0	0.3	—	0.2
1.1	0.3	0.3 (max.)	0.3 (max.)

The chromium is optional in the two steels containing it. The vanadium content is, however, of special importance because it helps to provide the combination of high surface hardness and internal toughness necessary for dies of this type.

When the dies are of the type that have been cold-hobbed, it is desirable to subject them to an annealing treatment designed to relieve strains. This comprises heating to within the temperature range 680 to 730° C. followed by slow cooling. Where the hobbing operation

* Fully described in "The Heat-Treatment of Steel"—*op. cit.*

involves the elimination of a good deal of material, it may be necessary to introduce intermediate annealings.

Forging should begin at 980° C. for the lighter sections and 1,100° C. for heavier sections involving considerable reduction, and should not be continued after the steel has cooled to 820° C. A normalising after forging is advantageous. In heating-up for forging, the steel should be brought slowly to a temperature of 790° C. and then quickly to the forging temperature.

Normalising involves reheating the steel slowly to 790° C., then rapidly to 870 to 900° C., according to the carbon content, the higher temperature being for the higher carbon. The temperature should be maintained for from a quarter of an hour to an hour. If an annealing treatment is preferred, this consists in heating the steel gradually and evenly to 740 to 780° C., the higher end of the range corresponding to the higher carbon content. The temperature should be maintained from one to four hours, according to the dimensions of the die, and cooling should not be at a faster rate than 25° C. per hour until the temperature of 540° C. is reached.

To ensure thorough penetration of the heat at the hardening temperature, and to reduce the period required in the hardening furnace, a preheating operation is advisable. Dies made from these steels should be pre-heated slowly and evenly in a furnace maintained at a temperature of from 540 to 550° C. in advance of their transfer to the actual hardening furnace. The hardening furnace should be maintained at a temperature between 780 to 870° C., the precise temperature being governed by the dimensions, form and character of the die impression and by the composition of the steel. The higher temperatures are suitable for the dies of greater mass but in the main a hardening temperature between 790 and 810° C. produced a suitable tool. The temperature is maintained long enough to ensure thorough penetration, and is then quenched in water.

If the dies are solid and have deeply cut impressions, the water must be forced under pressure into these impressions or through any holes, to prevent the formation of "pockets" of vapour or gas, and to make certain that an adequate amount of the fresh cooling medium comes into contact with the areas required hard. Where the dies are small, they are generally hardened by directing a water jet through the hole only. Dies of massive type can be entirely immersed in the quenching medium, which is also forced under pressure through the hole. When open dies are being hardened without the aid of a jig, it is better to quench them in a brine solution because in this way there is no risk that pockets of vapour will be trapped. Such pockets produce areas that are soft, because the quenching medium is effectively prevented from coming into contact with them.

The tempering operation should be carried out either at once or as quickly as possible after hardening. The range of temperature within which to temper is governed by the shape and character of the die and by the material on which it is to be used. Dies of heavy cross section should be tempered at about 150° C. Those of smaller cross-section should be tempered at from 250 to 300° C. according to the purpose. Usually it will be found that tempering between 200 and 220° C. meets most requirements. Care should be taken to ensure that the tempering temperature is maintained long enough to produce the desired result. This involves a duration of not less than 1½ hours, which usually serves the purpose.

The great point with all these steels is that they must

be given a degree of hardness that varies as little as possible over the area of the die, and that penetrates as deeply as possible, so as to enable the steel to withstand the great pressures brought to bear upon it.

These steels can also be used for hammer pistons, and to harden them for this work, they should be quenched in water at 820° C. and tempered at 200° C. for from two to three hours.

Cold drawing of sections of unalloyed carbon steel and low-alloy steels, with Brinell hardness numbers up to 230 before they are drawn, is now being carried out with a steel of tungsten type, a typical composition of which is 1.4% carbon, 2.5% tungsten. This steel is forged within the temperature range 950 to 1,000° C., and can be annealed at 730° C. The dies should be pre-heated to 600 to 650° C. and hardened by heating to 820° C. and quenching in cold water. Tempering follows immediately after at 150 to 180° C., which should produce a Brinell hardness number of about 710 (950 Vickers Pyramid number).

Increasing Pig Iron Production

Continued from page 146

Apart from the instruments already mentioned, the stove control house contains an indicator and a recorder for the gas volume to the stoves, and recorders for the stove dome temperature, the CO₂ content of the flue gas, the blast temperature and the amount of gas in the gasholder. The Foster blast-temperature controller is also situated in the stove control house.

Duplicated in the winch house and on the charging panel near the skip pit, are indicators for stockline depth, bell dumping and distributor movement.

Operation

Since blowing-in, the furnace has been very regular in operation and has made over 100,000 tons of iron. The present weekly output of about 4,800 tons, is achieved with a coke consumption of a little under 16 cwt. per ton of iron. One of the main operating difficulties is that of obtaining adequate supplies of each particular type of ore. Changes of burden are often necessitated by this uncertainty of supplies. Roughly, the ore charged is 25-30% sinter, 10-30% Mediterranean, 20-40% Wabana and the rest Swedish. The flux charged consists of about two-thirds basic slag to one-third limestone. As the basic slag contains some iron and manganese, it would be misleading to present ore and flux figures, but the total of ore and flux charged is about 40 cwt. per ton of iron.

The two older furnaces are not now being driven at their maximum rate, but the combined output of the plant is around 11,000 tons per week, of which about 2,500 tons per week is delivered to the hot-metal mixer at Clydebridge steelworks. The remainder is cast in the two Ashmore, Benson, Pease double-strand pig casting machines for use in the cold pig and scrap process at other works.

Whilst a great deal of the Scottish steel output will continue to be made by the traditional cold pig and scrap process, as and when increases in output are brought about it will be essential to use more pig iron, and this will be done by the hot-metal process.

Acknowledgment is made to the Directors and Staff of Colvilles, Ltd. for the provision of data and photographs and for permission to publish these details of their plant.

Nodular Cast Irons

Their Production and Properties

By H. Morrogh and J. Grant

(British Cast Iron Research Association).

Until recently the only method of obtaining the graphite in a cast iron in a nodular form was by a lengthy annealing process. As a result of much research work on the fundamental aspects of graphite formation, the British Cast Iron Research Association has developed a process whereby graphite formed on solidification is in the nodular form. The resulting iron whilst not as good as malleable iron is a very distinct improvement on normal flake graphite irons and the process can be hailed as one of the most outstanding developments in the field of cast iron metallurgy. In a recent paper to the Institute of British Foundrymen, Messrs. Morrogh and Grant outlined the method and the properties attainable thereby. The paper is presented here in an abridged form by courtesy of Mr. J. G. Pearce, Director of the British Cast Iron Research Association and of the authors.

INTRODUCTION

IT is well known that ordinary grey cast iron contains free carbon or graphite distributed through the metal in the form of flakes or lamellae. These graphite flakes severely limit the mechanical properties of the material, rendering it relatively brittle and non-ductile. In malleable cast iron, the free carbon exists in the form of temper carbon nodules which consist of approximately spheroidal aggregates of graphite. Graphite in the form of nodules does not appear to exert such a deleterious influence as when the same amount of graphite occurs in the form of flakes. These facts are well known and have been illustrated and discussed in the literature upon innumerable occasions. Furthermore, it has always been obvious that if cast iron could ever be produced with the graphitic carbon in the nodular form, an improvement in mechanical properties should result.

In the past the achievement of this ideal nodular structure in as-cast grey irons has not appeared to be possible, since nodular graphite was only produced by the heat-treatment of white cast iron according to the conventional malleabilising process. However, following a long-term investigation in the laboratories of the British Cast Iron Research Association, a process* has recently been developed by which grey cast iron can be obtained, having all or part of the graphitic carbon content in the form of nodules in the as-cast state, without the necessity for applying a subsequent heat-treatment for the purpose of obtaining that structure. Irons produced by this process, and having this structure in the as-cast state, have been termed "nodular cast irons."

Morrogh and Williams^{1, 2} have given an account of the preliminary work leading up to the prediction of the possibility of producing nodular cast irons. More recently^{3, 4} the same investigators have given accounts of the development of the process and of some of the theoretical considerations underlying it. It is the purpose of the present Paper to give a detailed description of the mechanical properties of typical nodular irons

and to discuss the commercial production of the material. Only a bare outline of the process will be given here, and for further details about the metallurgy of the process and the methods of investigation which have been used, attention is drawn to the other accounts, especially references³ and ⁴. For a full understanding of the process, consultation of these references will be necessary.

The Process for the Production of Nodular Cast Irons.

Stated in its simplest form, the process involves the solution of an appropriate amount of cerium in molten cast iron of appropriate composition shortly before casting. The principal composition requirements for the iron to be treated with cerium are:—

(1) The iron must solidify grey even without the cerium addition.

(2) The iron must be of hyper-eutectic carbon content, that is the carbon content should exceed the value $4.3 - \frac{1}{2}(\text{Si \%} + \text{P \%})$

When the nickel content of an iron exceeds 10% it need not be hyper-eutectic according to this formula.

(3) The silicon content can have any value, but is preferably within the range 2.3 to 7%.

(4) The sulphur content of the metal to be treated should be as low as possible and after treatment it should not exceed 0.02 %.

(5) The phosphorus content must not exceed about 0.6% and should preferably be below 0.1%.

(6) Manganese, copper, nickel, chromium and molybdenum may be present in any amounts, singly or in any combination, provided condition No. 1 is observed.

The most important of the above requirements are those covering the carbon and sulphur contents. After treatment with cerium the solidified castings must contain more than 0.02% of this element.

The Influence of Cerium in Cast Iron

First and foremost, cerium combines with sulphur in cast iron and is a very effective de-sulphuriser. Cerium itself will not alloy with cast iron until the sulphur content of the material has been reduced below about 0.02%. When cerium is added to molten cast iron

* This process has been made the subject of various British, British Empire and foreign patent applications.

¹ Morrogh, H., and Williams, W. J., *Journal of the Iron and Steel Institute*, 1947, March, pp. 321-371.

² Morrogh, H., and Williams, W. J., Paper No. 875, 44th Annual Meeting, 1947, Institute of British Foundrymen.

³ Morrogh, H., and Williams, W. J., *Journal of the Iron and Steel Institute*, 1948, March.

⁴ Morrogh, H., *American Foundryman*, 1948, April.

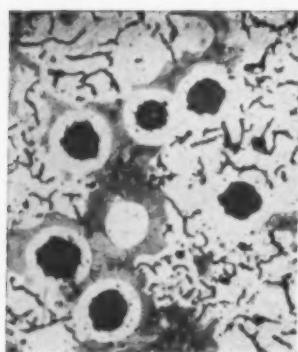


Fig. 1.—General structure of cerium-treated hyper-eutectic cast iron. Etched in picric acid. $\times 100$.

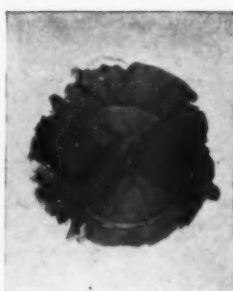


Fig. 2.—Duplex structure of hyper-eutectic nodule. Unetched. $\times 1,500$.

All photomicrographs reduced $\frac{1}{2}$ linear dimensions

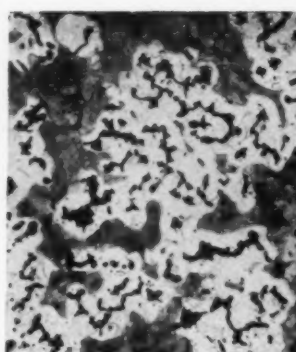


Fig. 3.—Quasi-flake graphite in single-treated nodular iron. Etched in picric acid $\times 100$.

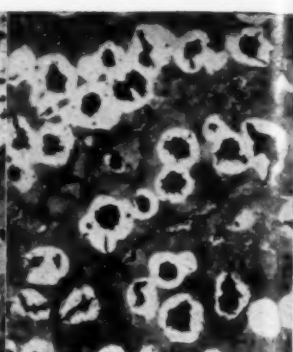


Fig. 4.—Nodular structure in double-treated nodular iron. Etched in picric acid. $\times 100$.

containing sulphur in excess of this figure it immediately combines with the excess sulphur to give a cerium-sulphur compound which is relatively insoluble in molten cast iron and floats to the surface of the metal. This de-sulphurising reaction is very rapid; for instance, the sulphur content of 5 cwt. of molten metal may be reduced from 0.06% to below 0.02% in a few seconds by the addition of an appropriate amount of cerium. The process for the production of nodular cast iron depends firstly upon this de-sulphurising effect of cerium when the sulphur content of the iron to be treated exceeds about 0.015%.

When more than sufficient cerium is added to the molten cast iron to reduce the sulphur content to below 0.02%, or when the sulphur content is initially below this figure, the excess cerium dissolves in and alloys with the molten cast iron and then exerts a pronounced carbide-stabilising effect, that is, it tends to cause the iron to solidify white rather than grey. It is important to note that the carbide stabilisation only arises from cerium actually dissolved in the metal and not from cerium combined with sulphur.

Function of Cerium in Producing Nodular Graphite Structures

When cerium is added to a molten hyper-eutectic cast iron of appropriate composition (as described previously), so that the final sulphur content is below 0.02% and the cerium content is in excess of 0.02%, but below the amount which will give a white iron casting, on solidification it causes the hyper-eutectic graphite, which is deposited from the liquid before the metal

proper begins to solidify, to crystallise in the form of nodules. When the metallic part of the cast iron solidifies, it does so as a white cast iron giving the familiar white iron eutectic containing cementite (iron carbide) so that immediately after solidification there exist nodules of hyper-eutectic graphite distributed through a white iron structure. Due partly to the inoculating effect of the hyper-eutectic graphite nodules, the cementite of the white iron begins to decompose shortly after solidification to give more graphite.

The improvement in mechanical properties resulting from the cerium treatment is clearly indicated in Table I in which the mechanical properties obtained on two sets of test bars are tabulated. The bars were cast from two melts of the same iron to one of which the appropriate amount of cerium was added. The only significant differences in analysis were the reduction of sulphur from 0.023% to 0.007% due to the cerium treatment and, of course, the presence of 0.040% cerium.

The mechanical properties of the bars cast from the treated material are at a very much higher level and immediately fall into the range of properties covered by high-duty cast irons. The microstructure of a treated 1.2-in. bar is shown in Fig. 1. The hyper-eutectic nodules can be clearly seen, together with a form of graphite somewhat resembling flake graphite in a matrix of ferrite with some pearlite. The "flake-form" of graphite is that resulting from the decomposition of the eutectic carbide after solidification and to distinguish it from normal flake graphite it has been termed "quasi-flake" graphite. This term will be used throughout this Paper to describe this form of graphite.

TABLE I.—INFLUENCE OF CERIUM ON REMELTED HEMATITE PIG-IRON

Diam. of test bars in.	Transverse rup. stress Tons/sq. in.		Deflection in.		Tensile strength Tons/sq. in.		Brinell hardness number		Impact Ft.-lb.	
	Without Ce.	With Ce.	Without Ce.	With Ce.	Without Ce.	With Ce.	Without Ce.	With Ce.	Without Ce.	With Ce.
1.6	25.0	44.2	0.20	0.32	11.2	24.2	154	186	—	—
1.2	28.8	45.3	0.28	0.38	14.3	24.6	160	198	—	—
0.875	30.7	47.1	0.18	0.23	16.6	26.6	162	199	12	43
0.6	30.8	57.4	0.11	0.22	18.6	29.3	198	239	—	—

TABLE II.—INFLUENCE OF DOUBLE TREATMENT. CE + INOCULANT

No.	T.C.	Si	Mn	S	P	Ce	Transverse rup. stress Tons/sq. in.	Deflection in.	Tensile strength Tons/sq. in.	B.H.N.	Impact, ft.-lb.
1	3.67	2.67	0.86	0.005	0.051	0.040	56.9	0.60	26.0	221	54
2	3.49	2.89	0.88	0.008	0.055	0.038	62.0	0.60	33.4	258	84

If Fig. 1 be examined closely, it will be observed that around each hyper-eutectic nodule there exists a volume of metal which does not contain any quasi-flake graphite. This is due to the fact that the graphite arising from the decomposition of the cementite immediately surrounding each hyper-eutectic nodule is deposited upon the nodule instead of giving quasi-flake graphite. This is made particularly clear when one of these nodules is examined at a high magnification—the inner nucleus of hyper-eutectic graphite surrounded by a distinct periphery of graphite deposited on it can be clearly seen. A typical instance of this is shown in Fig. 2 where a hyper-eutectic nodule in a cerium-treated hyper-eutectic iron is illustrated at a high magnification.

Irons produced by the simple addition of cerium to the molten metal before casting, will usually have a microstructure consisting of a mixture of hyper-eutectic nodules, together with quasi-flake graphite. This process will be referred to as the "single treatment" process to distinguish it from a further elaboration of the process by which entirely nodular structures can be produced. With relatively low cerium contents the quasi-flake graphite is definitely in a flake-like form, but with relatively high cerium contents it tends to assume a nodular appearance, conferring a corresponding improvement in mechanical properties upon the resulting cast iron. Except in relatively heavy sections, it is not possible to utilise the latter effect of cerium, because of its pronounced carbide stabilising influence, which may cause the iron to remain white. It is obvious, therefore, that for the development of entirely nodular structures the process must be modified in some way to overcome this difficulty. This modification has been achieved by the introduction of what will be known as the "double treatment" process, which involves the addition of a graphitising inoculant to the molten metal simultaneously with, or immediately after, the cerium addition. By this double treatment process it is possible to obtain entirely nodular structures with the development of a new high level of mechanical properties.

It appears that each hyper-eutectic nodule has a sphere of influence within which further graphitisation takes place by deposition on the hyper-eutectic nodule and outside which quasi-flake graphite forms. It

follows, therefore, that if the number of hyper-eutectic nodules or nuclei could be increased so that their spheres of influence overlap, all the graphite will occur in the nodular form. The addition of the graphitising inoculant in the double treatment process has the effect of increasing the number of hyper-eutectic nodules. Suitable graphitising inoculants for this purpose are the 80% grade of ferro-silicon, S.M.Z.* or calcium silicide, but the first two are to be preferred to the latter.

Table II gives the analysis and mechanical properties of the two nodular cast irons cast in the form of 1.2 in. bars in greensand—No. 1 produced by the single treatment process and No. 2 by the double treatment process. In both cases the melt was treated with 0.14% cerium, but in the case of the double-treated iron 0.2% silicon was added as 80% ferro-silicon before casting.

The quasi-flake graphite structure of the single-treated bar No. 1 is shown in Fig. 3, and the almost entirely nodular structure of bar No. 2 in Fig. 4. The improvement in mechanical properties arising from the double treatment is clearly shown by the transverse, tensile and impact figures given in Table II. These are more or less typical figures, although much higher figures have been obtained, for instance for impact strength, and many other examples have already been given in the literature.^{3, 4}

Mechanical Properties of Nodular Cast Irons

Nodular cast irons must be regarded as new materials having mechanical and physical properties differing in many ways from those of high-duty grey cast irons on the one hand, and malleable cast irons on the other. In spite of the nodular graphite structure, nodular irons are still relatively brittle and non-ductile materials, and whilst, for instance, they have a shock-resistance inferior to that of the best grades of malleable iron, they are much less brittle than grey irons containing the usual flake graphite structures. The development and application of a new material of this type entails the determination of a wide range of mechanical properties other than those usually reported, such as transverse rupture stress, tensile strength, hardness, etc. The designer is interested, for instance, in the fatigue,

* S.M.Z. is a proprietary silicon-manganese-sirconium alloy containing approximately 63% silicon, 6% manganese, 6% zirconium, and 20% iron.

TABLE III.—KEY TO MELT NUMBERS—COMPOSITION AND STRUCTURE

Melt No.	Treatment and Additions	Chemical Composition							Structure
		T.C. %	Si %	Mn %	S %	P %	Ce %	Cu %	
V.835	Single. 70 gm. <i>mischmetall</i> to 65 lb. tap.	3.74	2.65	0.53	0.006	0.024	0.053	—	Quasi-flake graphite and a few hyper-eutectic graphite nodules in a matrix of ferrite and pearlite. V.835 was white in the 0.875 in. and 0.6 in. bars. V.980 was white in the 0.6 in. bar.
V.980	Single. 35 gm. <i>mischmetall</i> to 70 lb. tap.	3.76	2.48	0.85	0.012	0.051	0.029	—	
V.895	Double. 70 gm. <i>mischmetall</i> to 65 lb. tap. 64 oz. S.M.Z.	3.55	3.01	0.89	0.004	0.044	0.053	—	
W.3	Double. 90 gm. <i>mischmetall</i> to 70 lb. tap. 10 oz. S.M.Z.	3.60	2.33	0.84	0.011	0.044	0.045	2.19	Nodular structure with some quasi-flake graphite in the 1.6 in. and 1.2 in. bars of W.3. The matrix was almost entirely pearlitic, the ferrite decreasing with decreasing section.
W.30	Double. 110 gm. <i>mischmetall</i> to 70 lb. tap. 10 oz. S.M.Z.	3.68	2.34	0.77	0.009	0.035	0.054	1.49	
W.172	Inoculated.	3.04	1.92	0.84	0.032	0.041	—	—	
Nod. 67	Single. 42 gm. <i>mischmetall</i> to 60 lb. tap.	3.85	2.69	0.49	0.012	0.028	0.029	—	Quasi-flake graphite.
W.7	Double. 65 gm. <i>mischmetall</i> to 80 lb. tap. 9 oz. S.M.Z.	3.56	2.82	0.81	0.012	0.035	0.034	—	Nodular graphite.
V.83	8 oz. Fe Si (80%) to 80 lb. tap.	2.91	2.16	0.64	0.025	0.028	Ni 1.92	Mo 1.18	Flake graphite. Acicular.

Mischmetall is an addition containing 50% cerium.

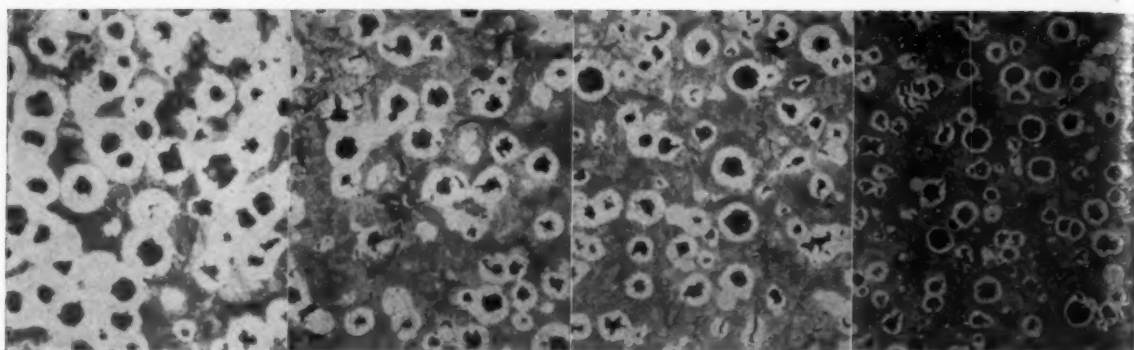


Fig. 5.—General structure of 1.6-in. bar, V.895. Etched in picric acid. $\times 100$.

Fig. 6.—General structure of 1.2-in. bar, V.895. Etched in picric acid. $\times 100$.

Fig. 7.—General structure of 0.875-in. bar, V.895. Etched in picric acid. $\times 100$.

Fig. 8.—General structure of 0.6-in. bar, V.895. Etched in picric acid. $\times 100$.

damping and elastic properties of the material and, whilst the metallurgical aspects of the process have been dealt with in some detail already^{3,4} in the literature no attempt has yet been made to present a detailed survey of the special mechanical properties. An attempt to do this will be made in this section of this Paper, but it is realised that the results given represent only a very rough preliminary outline of all the information required.

The particulars of the melts used for determining the mechanical properties are given in Table III. The first five melts listed were used for the majority of the tests, melt W172 being included for comparison as representing the high-duty flake graphite irons. The last three irons listed were used in the investigation of the fatigue properties of nodular irons. In Figs. 5–8 are shown the general structures of the 1.6 in., 1.2 in., 0.875 in. and 0.6 in. diameter bars of V895, a double-treated melt, whilst Figs. 9–12 show the structures of the 1.2 in. diameter bars of melts V835, V980, W3 and W30.

In Table IV the results of standard tests carried out on five nodular irons and the high-duty flake graphite iron are listed.

Transverse Tests.—By measuring the permanent set and total deformation for each load, it is possible to divide the total deformation into its plastic and elastic components. Fig. 13 shows the elastic, plastic and total deformation for the high-duty flake graphite iron W172 together with the plastic deformation for V835 and

V895. It will be noted that although the plastic deformation is less for nodular irons than for the flake graphite iron at low loads, there is considerable plastic deformation at high loads in the case of the nodular irons. Although not shown on the graph, the modulus of elasticity for nodular irons, at $18\text{--}26 \times 10^6$ lb./sq. in., is higher than that for high-strength flake graphite acicular irons which is about $16\text{--}18 \times 10^6$ lb./sq. in.

Tensile Tests.—The total strain in tensile testing was again divided into its plastic and elastic components, but the tests were only continued up to 50–60% of the ultimate tensile strength to avoid the risk of a testpiece breaking with the extensometer attached. Fig. 14 shows the results on W172 together with the plastic deformation for V835 and W30. Similar features to those of Fig. 13 may be noted but the large deformation at high loads is not brought out in Fig. 14 due to the tests being discontinued at 50–60% of the tensile strength.

Although the nodular irons exhibit a much greater total elongation at fracture than do the flake graphite irons, there is no yield point or necking such as is observed with malleable irons. An elongation of 5.5% has been recorded but the figure does not usually exceed 3%.

Hardness Tests.—The Brinell hardness numbers of nodular cast irons tend to be slightly higher than of untreated irons of otherwise similar analysis.

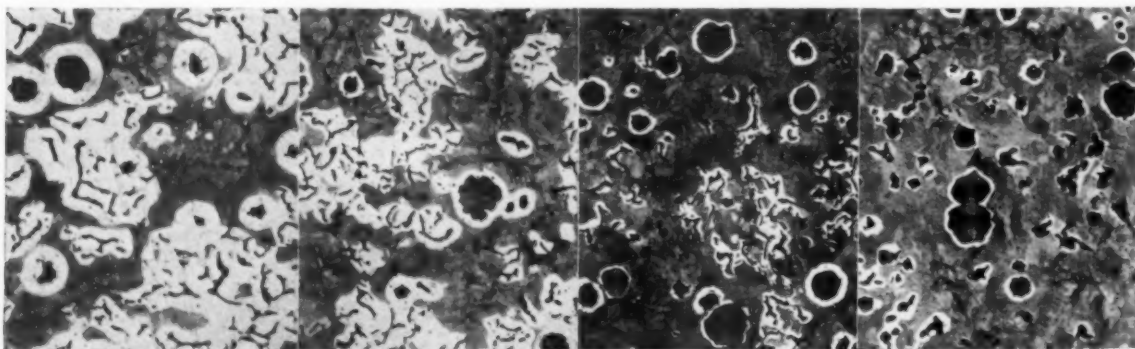


Fig. 9.—General structure of 1.2-in. bar, V.835. Etched in picric acid. $\times 100$.

Fig. 10.—General structure of 1.2-in. bar, V.980. Etched in picric acid. $\times 100$.

Fig. 11.—General structure of 1.2-in. bar, W.3. Etched in picric acid. $\times 100$.

Fig. 12.—General structure of 1.2-in. bar, W.30. Etched in picric acid. $\times 100$.

TABLE IV.—MECHANICAL TEST RESULTS ON FIVE SAMPLES OF NODULAR CAST IRONS

Melt No.	Diam. As-cast In.	Transverse as-cast			Transverse machined			Tensile		Ratio Trans.	B.H.N.	Impact, 0.798 in. diam., ft.-lb.	Compression	
		Trans. rup. stress Tons/sq. in.	Deflection In.	Mod. of elasticity $\times 10^6$ lb./sq. in.	Trans. rup. stress Tons/sq. in.	Deflection In.	Mod. of elasticity $\times 10^6$ lb./sq. in.	Ult. tensile stress Tons/sq. in.	Mod. of elasticity $\times 10^6$ lb./sq. in.				Ult. compression stress T./sq. in.	Mod. of elasticity $\times 10^6$ lb./sq. in.
										Tens.				
V.835	1-6	40.7	0.34	18.2	45.0	0.43	18.9	23.0	19.4	1.8	178	48 51	54.4	20.8
	1-2	48.6	0.54	20.5	47.1	0.57	20.0	25.6	20.8	1.9	187	32 51	76.0	
	0-875													
	0-6													
All 0-875 in. and 0-6 in. diameter bars were white														
V.880	1-6	48.5	0.47	19.4	47.2	0.59	19.0	22.4	20.2	2.2	178	51 33	54.8	21.3
	1-2	48.1	0.48	20.8	51.4	0.88	20.8	24.0	20.2	2.0	184	75 110	62.0	
	0-875	64.2	0.38	22.2	55.7	0.51	21.8	25.4	19.1	2.5	204		56.4	
	0-6													
All 0-6 in. diameter bars were white														
V.895	1-6	61.6	0.52	22.0	63.2	0.63	21.6	28.8	23.8	2.1	213	78 62	71.6	23.6
	1-2	70.2	1.03	23.4	69.6	0.95	23.4	30.6	24.1	2.3	220	55 59	66.0	
	0-875	73.4	0.44	24.9	63.2	0.29	25.0	35.2	24.0	2.1	249	100 120	72.4	
	0-6	77.6	0.36	21.9	80.2	0.36	22.8	34.8	21.4	2.2	272		70.0	
W.3	1-6	65.4	0.33	22.1	69.4	0.45	21.4	37.2	22.8	1.8	258	78 55	74.8	23.5
	1-2	72.9	0.50	23.3	77.8	0.70	22.4	38.0	22.1	1.9	272	100 100	75.2	
	0-875	73.8	0.26	24.0	79.2	0.32	22.1	38.2	22.8	1.9	290	100 120	67.2	
	0-6	77.0	0.18	24.7	80.8	0.23	23.3	38.6	23.4	2.0	313		93.6	
W.30	1-6	68.4	0.42	22.1	73.8	0.58	22.1	34.2	24.2	2.0	262	110	—	23.8
	1-2	71.9	0.54	22.8	64.0	0.42	23.1	37.8	23.4	1.9	271	55 73	66.4	
	0-875	82.7	0.37	26.0	73.2	0.28	23.1	38.0	24.4	2.2	290	56 72	78.2	
	0-6	93.6	0.37	24.3	90.0	0.28	23.9	36.6 ^a	23.4	2.6	307		84.0	
† W.172	1-2	44.9	0.43	15.8	—	—	—	21.7	14.2	—	—	—	—	—

† Flake graphite iron

* Fracture showed inverse chill.

Impact Tests.—The impact test results recorded in Table IV were carried out on plain cylindrical test pieces of 0.798 in. diameter in accordance with B.S.S.1349. For a low phosphorus pearlitic flake graphite iron the values in such a test would be about 20 ft.-lb., for a high-duty acicular iron 30–40 ft.-lb. and a good quality flake graphite austenitic iron would withstand 120 ft.-lb. without fracture. Although somewhat erratic, the results do show the order of shock resistance of nodular cast irons, and it may be noted that the lowest value obtained is as high as most high-duty acicular irons would give. The beneficial results of double treatment are also apparent from a study of Table IV.

Although the high shock resistance is one of the most

important properties of nodular iron, it is still brittle compared with steel and malleable iron as shown by the fact that an iron which gave a value of over 100 ft.-lb. on the standard tests, when machined down to standard Izod test piece size gave values of 4.0 and 0.5 ft.-lb. for plain and notched test pieces respectively.

Compression Tests.—Compressive strength tests were carried out on 0.564 in. diameter $\times 1\frac{1}{2}$ in long test pieces. In considering the fact that the compressive strength/tensile strength ratio is 2–3 as compared with 3–4 for flake graphite irons it should be noted that in the

Fig. 15.—Structure of compression test-piece V.895 after fracture. Etched in picric acid. $\times 100$.

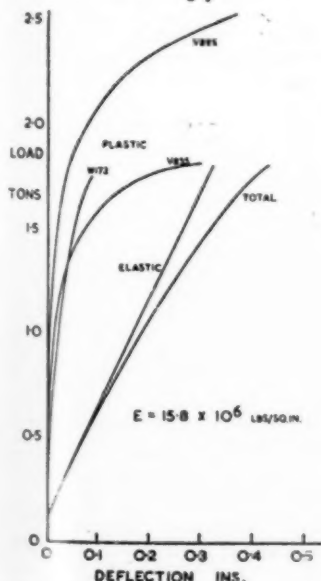


Fig. 13.—Transverse set and deflection curves for flake-graphite iron, W.172. 1.2 in. bar.

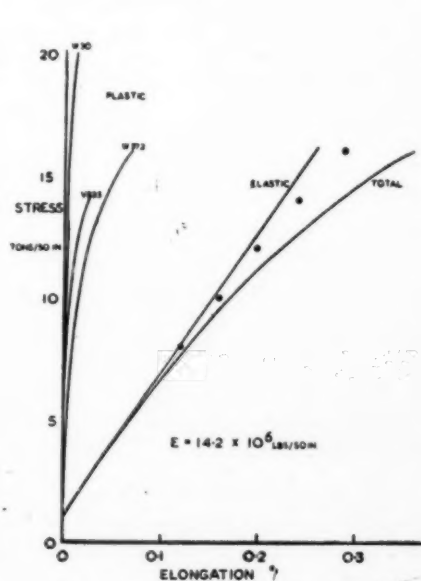


Fig. 14.—Tensile set and extension curves for flake-graphite bar W.172. 1.2 in. bar.

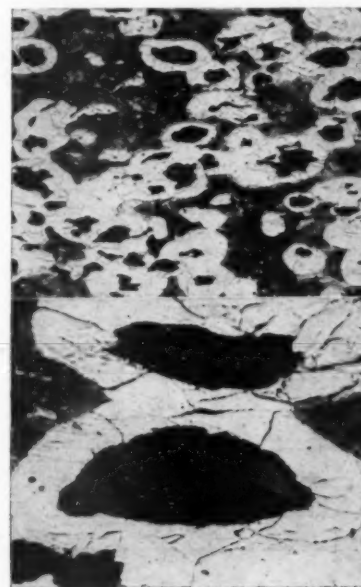


Fig. 16.—Same as Fig. 15, but at $\times 500$.

nodular iron tests there was considerable shearing over of the test piece. The construction of the machine offered little resistance to such shearing action.

Extensometer tests were also made over the early part of the curve on longer test pieces and the elastic, plastic and total deformation plotted. The moduli of elasticity in compression are very similar to the moduli in tension.

TABLE V.—TORSION TEST RESULTS

Melt No.	Torsion	
	Ultimate torsional shear stress, Tons/sq. in.	Modulus of rigidity $\times 10^6$, Lb./sq. in.
V.825.. .. .	24.8	8.3
V.880.. .. .	26.1	8.2
V.895.. .. .	31.8	9.6
W.3	37.5	9.2
W.30	> 40	9.7

Figs. 15 and 16 show the structure of a compression test piece after fracture and illustrate the ability of the graphite nodules to withstand appreciable distortion without rupture.

Torsion Tests.—Torsion tests were carried out on machined bars in three ways: (1) The angle of twist was recorded for each 500 lb.-in. increment of torque up to fracture; (2) the total twist and permanent set were recorded against torque; (3) a hysteresis loop was obtained by applying a cycle of loading. The ultimate torsional shear stresses and moduli of rigidity are given in Table V, and it will be seen that the ultimate torsional stresses are very close to the ultimate tensile stresses. The total twist at fracture was usually about 90°, corresponding to about 10% strain. As had been found in compression testing, a rapid increase in strain occurred when the torque exceeded about 50–60% of the breaking torque. For the limited stress range that the set and twist curves cover they are very similar to the corresponding curves for transverse and tensile tests. The elastic points, derived by subtracting the plastic from the total twist, likewise curve towards the total twist line as the stress increases as may be seen in Fig. 17.

Damping Capacity.—The high damping capacity of flake graphite irons is attributed to the presence of the

TABLE VI.—FATIGUE TESTS OF THE IRONS DETAILED IN TABLE III

Melt No.	Tensile, tons/sq. in.	Fatigue limit	Endurance Ratio, (Tensile)	Structure
			(Fatigue)	
V.980.. .. .	25.4	15.0	0.59	Quasi-flake, ferrite and pearlite.
V.895.. .. .	35.2	16.0	0.46	Nodular, ferrite and pearlite.
W.3	38.2	18.5	0.48	Nodular, pearlite.
NOD.67	24.1	12.0	0.50	Quasi-flake, ferrite and pearlite.
W.7	30.5	17.5	0.57	Nodular.
V.636.. .. .	33.9	11.5	0.34	Flake, acicular.

graphite flakes. It would be expected, therefore, that nodular irons would have a damping capacity more like mild steel and this has been shown to be the case. Tests taken on a Cambridge torsional damping capacity machine gave the results shown in Fig. 18 in which the materials are placed in the following order of increasing damping capacity: (1) Mild steel; (2) completely nodular irons; (3) nodular irons containing quasi-flake graphite; and (4) flake graphite irons.

Fatigue Tests.—A Wöhler-type machine was used for fatigue testing five nodular irons and one flake graphite acicular iron with the results tabulated in Table VI.

In addition to the straightforward fatigue tests, plain, notched and grooved test pieces were tested in tension and on the Wöhler machine. As will be seen from Table VII, although the data is insufficient to draw any definite conclusions, nodular irons do not appear to be notch sensitive in a static test but in a dynamic test they are more notch sensitive than flake-graphite irons. The latter, however, is considerably notch sensitive in both static and dynamic tests.

Shear Tests.—Although no shear tests have been carried out on the irons listed, previous results have shown that the ultimate shear stress is usually slightly below the ultimate tensile stress. The drop may vary from 2 tons/sq. in. at 24 tons/sq. in. ultimate tensile stress to about 6 tons/sq. in. at 34 tons/sq. in. ultimate tensile stress.

Electrical Resistivity.—The coefficient of electrical resistivity for a flake graphite iron is about 60–80 microhms/cm. cube as compared with 14 for wrought

TABLE VII.—FATIGUE STRENGTH OF PLAIN, GROOVED AND NOTCHED BARS

	NOD.67. Nodular			V.636. Flake acicular		
	Plain	0.05 in. Groove	45° Notch	Plain	0.05 in. Groove	45° Notch
Tensile, tons/sq. in.	24.1	26.4	25.9	33.9	30.6	26.4
Fatigue limit, tons/sq. in.	12.0	8.5	7.0	11.5	8.5	9.0
Endurance ratio, $\frac{\text{Tensile (plain)}}{\text{Fatigue}}$	0.50	0.35	0.29	0.34	0.27	0.25
Endurance ratio $\frac{\text{Tensile (notched)}}{\text{Tensile (plain)}}$	—	0.32	0.27	—	0.29	0.32
Static stress concentration factor, $\frac{\text{Tensile (notched)}}{\text{Fatigue (plain)}}$	1.0	0.91	0.93	1.0	1.11	1.28
Dynamic stress concentration factor, $\frac{\text{Tensile (notched)}}{\text{Fatigue (notched)}}$	1.0	1.41	1.72	1.0	1.28	1.35

TABLE VIII.—MECHANICAL PROPERTIES OF UNTREATED AND SIMPLE-TREATMENT NI-RESIST

	T.C. %	Si %	Mn %	S %	P %	Cr %	Cu %	Ni %	Ce %
Untreated	2.76	2.68	0.45	0.027	0.024	1.74	6.74	13.24	—
Treated	—	—	—	0.007	—	—	—	—	0.045

	Transverse rup. stress, tons/sq. in.	Deflection in.	Tensile strength, tons/sq. in.	Brinell hardness number
Untreated	29.2	0.47	12.2	146
Treated	47.4	0.86	20.3	185

TABLE IX.—CHEMICAL COMPOSITION OF THREE ALLOYED CAST IRONS

Melt No.	T.C. %	Si %	Mn %	S %	P %	Ce %	Ni %	Cu %	Mo %
V.985	3.58	3.07	0.80	0.008	0.040	0.038	2.04	—	0.58
W.57	3.42	2.96	0.81	0.007	0.042	0.036	—	2.51	0.64
W.79	3.32	2.95	0.82	0.014	0.031	0.039	2.15	—	0.69

iron and 17.6 for mild steel. The nodular irons at 60-65 are slightly lower than normal flake-graphite irons, but a flake-graphite iron of equivalent carbon content has a value of 100.

Thermal Expansion.—In the five nodular irons tested there was no variation in coefficient of thermal expansion, the values ranging from: 10.5×10^{-6} per °C. in the 20°-100° C. range to 13.8×10^{-6} per °C. in the 20°-700° C. range.

Special and Alloyed Nodular Irons

The process is also applicable to austenitic, martensitic and acicular cast irons and such irons show a pronounced improvement in mechanical properties consequent upon the development of the nodular structure.

Austenitic Cast Irons.—With nickel contents exceeding 10% the iron need not be hyper-eutectic according to the formula: $C \text{ in eutectic} = 4.3 - \frac{1}{2} (Si + P)$, and the process may be applied to irons such as Ni-resist within the limits of sulphur and phosphorus specified above.

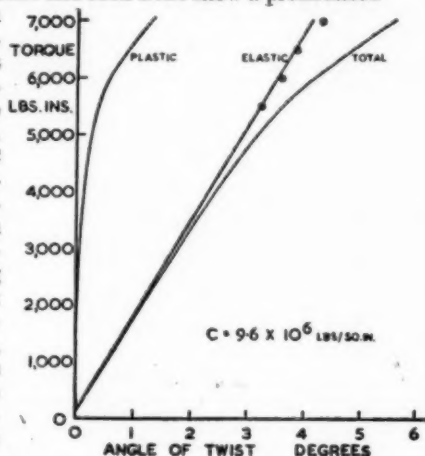


Fig. 17.—Set and twist curves for bar V.895.

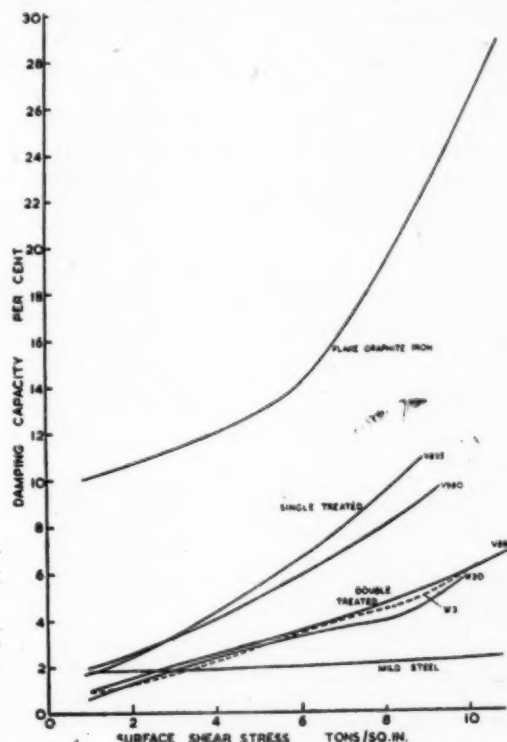


Fig. 18.—Variation of damping capacity with stress.

TABLE X.—MECHANICAL PROPERTIES OF THE IRONS DETAILED IN TABLE IX

Melt No.	Diameter as-cast	Transverse rup. stress Tons./sq. in.	Deflection, in.	Tensile strength, Tons./sq. in.	B.H.N.
V.985, As cast.	1-6 in.	81.2	0.45	37.1	352
	1-2 in.	72.1	0.47	39.8	401
	0-875 in.	78.2	0.30	32.5	492
	0-6 in.	63.5	0.17	Unmachinable	—
V.985, Tempered at 320° C. for 5 hours.	1-6 in.	77.4	0.31	47.4	373
	1-2 in.	89.9	0.47	42.6	412
	0-875 in.	90.1	0.25	43.2	451
	0-6 in.	125.1	0.28	51.7	477
W.57, Tempered at 320° C. for 5 hours.	1-2 in. 12 in. long.	—	—	40.4	242
	0-564 in. sha'd tensile.	—	—	46.0	285
W.79, Tempered at 320° C. for 5 hours.	1-2 in. 12 in. long.	—	—	50.8	335
	0-564 in. sha'd tensile.	—	—	55.2	325

Table VIII gives the mechanical properties of a single-treated and an untreated Ni-resist iron with 13% Ni, 6.7% Cu, and 1.7% Cr.

Nemag (12% Ni and 6% Mn) shows improvements in strength of 100-200% of the values for untreated material with an increase of 70 points in Brinell hardness.

The structure of cerium-treated austenitic irons consists of nodular graphite in a matrix of austenite with some carbide.

Acicular and Martensitic Cast Irons.—Nodular cast irons may be alloyed with nickel and molybdenum or with copper and molybdenum for the purpose of obtaining acicular or martensitic structures. As would be expected, nodular irons alloyed in this manner develop an extremely high level of mechanical properties which is capable of further improvement by tempering. Table IX gives the analyses of three such alloyed cast irons, and Table X gives their respective mechanical properties. Material V.985, which had a metallic matrix of the acicular structure and martensite together with

TABLE XI.—INFLUENCE OF HEAT-TREATMENT ON UNALLOYED NODULAR IRONS
Composition: T.C. 3.56%; Si, 2.88%; Mn, 0.54%; P, 0.035%; S, 0.007%; Ce, 0.048%

Bar size and treatment	Transverse rup. stress, tons./sq. in.	Deflection, in.	Tensile strength, tons./sq. in.	B.H.N.	Impact strength ft.-lb.
1-6 in., As-cast ..	45.1	0.43	—	—	—
1-2 in., As-cast ..	49.0	0.69	24.2	190	—
0-875 in., As-cast ..	54.6	0.35	—	—	47
0-6 in., As-cast ..	68.1	0.31	28.6	256	—
1-2 in., 900° C. oil-quenched, tempered, 3 hr. 450° C. ..	—	—	53.4	368	—
0-875 in., do. ..	—	—	55.6	363	—
0-875 in., slowly cooled from 900° C. ..	—	—	21.0	143	—
0-6 in., air-cooled from 900° C. ..	—	—	38.9	266	—

a little ferrite, was tested in the as-cast condition and after tempering at 320° C. for five hours, standard test-bars being used. Materials W.57 and W.79 were cast in the form of horizontal 1.2-in. bars each 12 in. long and as shaped tensile bars 0.564 in. diameter, and both were tested after tempering for five hours at 320° C. Material W.57 was only partially acicular, having about 50% of the matrix in the form of ferrite, whereas material W.79 had a good acicular structure together with a little ferrite around the nodules. All three materials were produced by the double-treatment process.

Heat Treatment of Nodular Cast Irons

"Dead" Annealing or Softening Annealing.—The object of this treatment is to make the material completely ferritic and hence in its most ductile form. With unalloyed irons of $\frac{1}{2}$ in. section with 3.5–3.9% carbon and 2.5–3.0% silicon this can be attained by heating to 700°–750° C. for 2 hours, but the most efficacious treatment is a slow cooling after heating at 900° C.

The results presented in the paper show that irons with a tensile strength of 25–30 tons/sq. in. lose about 3 or 4 tons/sq. in., whilst an iron with a strength of 37 tons/sq. in. has its strength reduced to about 29 tons/sq. in. by this treatment.

Quench Tempering and Normalising.—Table XI gives the results of tests taken to show the effect of heat-treatment on an unalloyed nodular iron. Nodular irons respond to heat-treatment in the same way as grey irons, the order of increase in tensile strength being about 30% for normalising and 100% for quenching and tempering. The as-cast structure of the iron concerned consisted of graphite nodules and quasi-flake graphite in a matrix of ferrite and pearlite. Normalising resulted in a matrix of fine pearlite, quenching and tempering in a martensite matrix and slow cooling in a completely ferritic matrix.

The Production of Nodular Cast Irons

From the foregoing summary of the mechanical properties of a few typical nodular irons it will be readily appreciated that they possess many attractive features. The problem arises as to how this new cast iron can be produced commercially and on an industrial scale.

An appreciable saving in cost is achieved by using *mischmetall* instead of cerium as the addition. *Mischmetall* which is commercially available contains about 50% of cerium and 50% of other rare earths. The *mischmetall* dissolves readily in molten iron without appreciable loss due to oxidation provided it is not allowed to float on top. Incidentally remelting a cerium treated iron results in loss of cerium and a return to a flake-graphite structure.

As mentioned earlier the sulphur content of the metal to be treated must be low, otherwise an excessive amount of cerium will have to be added to reduce the sulphur content. With electric furnace and crucible furnace melting it is possible to produce nodular irons merely by adding cerium to the molten metal but even though a sufficiently high carbon content can be maintained by using an all-pig charge in cupola melting there is usually some sulphur pick-up and a de-sulphurising treatment is necessary. With sulphur contents up to 0.08% a single treatment should suffice, but in excess of this figure a "double ladle" technique may be necessary.

After the de-sulphurising reaction has subsided the slag may be thickened and skimmed off. The cerium followed by the inoculant may then be added and stirred in, or the metal may be poured into another

ladle containing the additions. Although it is necessary for the cerium to dissolve before the inoculant, it has been found that with 80% ferro-silicon and S.M.Z. as inoculant the *mischmetall* and the inoculant may be put at the bottom of the ladle together and the metal poured on to them. Apparently the *mischmetall* dissolves more rapidly than the inoculant and the correct order of solution is obtained. The optimum temperature for treatment is 1,350°–1,450° C. as below 1,300° C. some flake graphite may separate out before the addition is made.

The phosphorus content of the metal must be as low as possible, preferably below 0.1%. With phosphorus contents exceeding 0.5% it is impossible to dissolve sufficient cerium to have the desired effect.

Metal coming from the blast furnace is often of ideal composition for cerium treatment and it may provide a relatively cheap way of making nodular iron castings near the furnace. Alternatively, the use of a basic cupola may provide means of obtaining irons with high carbon and low sulphur contents with at least an appreciable part of the charge made up of steel scrap.

Conclusions

It must be immediately pointed out that the material, whilst having some of the microstructural characteristics of malleable cast iron, does not possess the mechanical properties of conventional malleable cast iron. Nodular cast irons are still relatively non-ductile and brittle and they do not exhibit a yield point, although their shock-resistance is very much superior to that of the best high-duty flake-graphite irons. There are obvious reasons for this difference between the nodular cast irons and malleable cast irons. Nodular cast irons have, compared with most malleable cast irons, relatively high carbon and high silicon contents, and in the as-cast state are subject to all the heterogeneity of any as-cast material. There is evidence that by appropriate heat-treatment nodular cast irons may develop a measure of ductility, but this is still largely a matter for future work.

Compared with flake-graphite irons, nodular cast irons can be produced having transverse rupture stresses and tensile strengths as good as, and better than, those of accepted high-duty cast irons. In addition, these high values may be obtained at a relatively low level of hardness and with shock-resistance figures as high as two to four times those of high-duty grey cast irons.

The damping capacity of nodular cast irons is appreciably lower than that of any flake-graphite cast iron. The evidence available suggests that nodular cast irons are more notch-sensitive than grey irons in a dynamic test, but less sensitive in a static test. Stress/strain curves for nodular cast irons are essentially of the same type as those for flake-graphite irons, but nodular cast irons are characterised by relatively lower plastic strain at low, and relatively high plastic strain at high loads. It will be seen from these brief comments that nodular irons possess mechanical properties which might render the material particularly suitable in the field of engineering applications where high strength and shock-resistance are required, together with good machinability. By appropriate heat-treatment or by the use of special alloying elements the mechanical properties of nodular cast irons can be raised to a very high level, but interest in nodular cast irons quite naturally centres around the use of the unalloyed material in the as-cast state.

Furnace Pressure Control in Relation to Performance

By C. H. Stone

The author has endeavoured to set down in the following notes his conception of furnace-pressure control, and its importance in relation to the performance of open-hearth and other industrial furnaces. In order to consider the subject in any detail, however, he has sought to establish the fundamental nature of what is termed "furnace pressure" which is so necessary in understanding the principles underlying the need for its control.

IN emphasising the importance of furnace-pressure control in relation to the performance of open-hearth and other industrial furnaces it is necessary to consider the term "furnace pressure." An essential preliminary is to establish a balance between the volume of the combustibles entering the chamber or laboratory where the heat transfer takes place and the volume of the products of combustion which is withdrawn by a force commonly known as chimney draught. The fuel and air, supplied to the combustion chamber in the volumes required for combustion and the necessary heat transfer, have, after combustion has taken place, to be removed to make way for further volumes of fuel and air in order that the requisite heating conditions may be maintained.

A chimney force, or suction will, therefore, be required which will, at any instant, be related to and be capable of dealing with the volume of combustibles which is being supplied to the furnace. If this force is out of balance and is, say, greater than is necessary to evacuate the products of combustion, then it will attempt to restore the balance by whatever means are available. What are these means?

The chimney suction is attempting to draw into the furnace more than is being supplied to it—i.e., it is trying to increase the volume of combustibles. This condition will, however, only occur in cases where one is dealing with totally-enclosed furnaces, the nearest practical example being that of a steel-cased (not just brick-cased) boiler combustion system. For most furnaces this condition does not apply, brick walls not making a totally-enclosed system. Cracks and fissures, doors, etc., provide openings to the surrounding atmosphere. Expansion and contraction of arches, roofs, etc. leave gaps, which, small in themselves, represent in total quite a considerable area.

If, therefore, this chimney force is more than enough at any instant to remove the volume of the combustion gases, these apertures will afford a path through which the deficiency between the volume supplied and the volume which the chimney draught is capable of withdrawing will be readily made up. This condition is commonly known as air infiltration, and is the result of lack of equilibrium between incoming and outgoing volumes. It must, of course, be understood that there is not a direct relationship between these two volumes, since the outgoing volume is the result of the product of the combustion of the incoming volumes of fuel and air. This relationship is not, therefore, a simple one, and will vary according to conditions of combustion and the temperature within the chamber.

Disregarding, for the moment, other influences, this lack of balance creates a vacuum within the combustion chamber which is relieved by the infiltrating air. Such a condition will exist as long as the chimney force or suction is too great. One will obviously attempt to reduce this force until a state of balance is realised—i.e., until the static conditions inside the furnace most nearly balance the static conditions outside. Then the chimney draught will be just sufficient to withdraw the products of combustion only. It appears clear, therefore, that one must establish a static condition within the chamber which is just equal to or slightly higher than that of the surrounding atmosphere.

When it is considered that the draught withdrawing the combustion products is not only created by chimneys, but also by exhausters, fans, etc., the establishment of the right balance becomes a problem of some importance.

But this is not the only problem. Consider the path followed by a gas particle from its entry at the port to its final discharge. It will first of all be influenced by the exit velocity from the port, a velocity which it will lose gradually or suddenly according to design of burner or port. Eventually, it will reach a point where its velocity and path will be influenced less by its own kinetic energy and more by the chimney suction. It has, on its journey, been subjected both to a push and a pull and the point of conversion will be called the "take-over." These points of "take-over" for all the gas particles will, if joined together, form a substantially plane vertical surface which may be called the "take-over" plane within the combustion chamber. This means that from port to port there will first of all be a reduced gas velocity as each particle loses its kinetic energy, and then an increasing velocity as the suction force preponderates after the "take-over." If one considers all these gas particles, the points of equal velocity along their paths will form planes, representing velocities from the incoming port from maximum to minimum speed and to the outgoing port from minimum to maximum speed. The best position for the vertical "take-over" plane will depend upon the construction of the furnace ports, the combustion chamber itself and on the apertures.

There are next to be considered the static conditions within the combustion chamber in relation with this vertical plane. Since one is dealing with a high-temperature furnace the buoyancy of the gases must be taken into account. These hot gases are forced upwards and create a pressure on the roof since it restrains their upward drift. The magnitude of this roof pressure will depend upon the furnace temperature and the height above the hearth or bath. This buoyancy effect can be

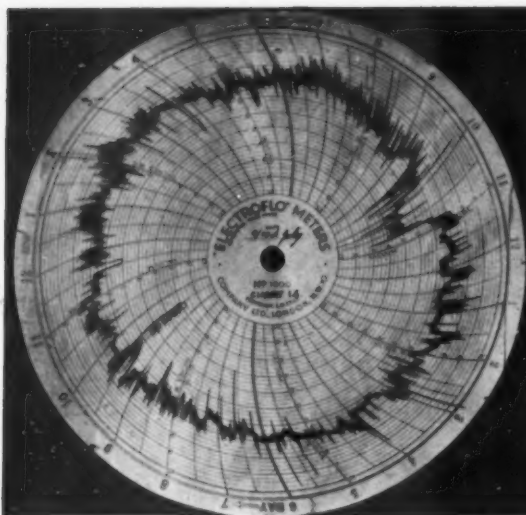


Fig. 1.—Typical pressure record of an open-hearth furnace.

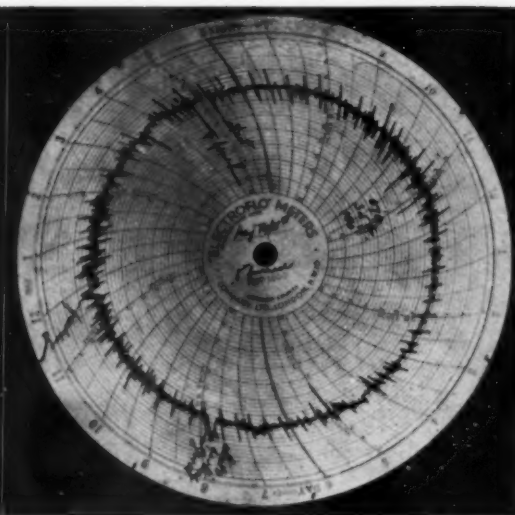


Fig. 2.—Pressure record taken from same furnace with automatic control.

calculated, a fact which is of considerable help in determining these minute static pressures, and practical tests have shown that such calculations are accurate.

It is essential that only static conditions should be measured—conditions which are free from any dynamic influences. A position must, therefore, be sought where the conditions are stagnant—i.e., where there is no flow, and, furthermore, a position which is unaffected by changes in flame, etc. Using the analogy adopted by W. E. Groume-Grjimaile in studying the flow of gases through a furnace, if the furnace is imagined to be inverted and with the flow of gases replaced by a flow of water, the position where the liquid becomes stagnant is generally at the lowest point in the water-filled chamber. The point of measurement is, therefore, chosen at the highest position in the centre of the furnace roof. The pressure at any point between the roof and the bath can then be determined by deducting from the measured roof pressure the buoyancy figure corresponding to the distance below the roof.

Before proceeding further, consider the effect of air infiltration, and so realise why it must be avoided in all circumstances.

This infiltrating air is, in relation to the hot gases inside the furnace, a very heavy gas. It will, therefore, fill the lowest parts of the combustion chamber. But, unfortunately, it is here where the transfer of heat is to take place. The net result is that this incoming stream of cold dense air diverts the less dense hot gases from their proper position in the chamber so that, not only do the wrong parts of the chamber receive the heat, but more fuel has to be used to get the same heat applied to the correct area. Since hot and cold gases do not readily mix, one has, also, involuntarily created changed flow conditions in the discharge systems such as down-takes, regenerators, recuperators, flues, etc., which will in turn influence brick erosion, dust deposition, carry over and buoyancy. The picture on the outgoing side is completely changed.

How often has it been noticed, especially by foremen bricklayers, when repairing furnaces in steel works, that there is such a big difference in the size of the uptakes

between stage and pit-side? The former is usually very much wider and more "washed out" than the latter which is generally found to be about its normal size.

But is air infiltration the only point to be considered? There is another aspect which is, perhaps, quite as vital.

It has already been noted how, by prevention of air infiltration, the most intense flame (the flame direction being assumed to be correctly established by proper port design) is allowed to be near the surface where the heat transfer is to occur. The flame development can take place unimpeded by any thick layer of cold air which diverts it from its object. There is no cold layer to chill the surface of the bath so long as a positive pressure is maintained near the bath or hearth level. While the highest point in the furnace roof has been taken as the point of measurement because it gives the simplest guide for corrective action, this lowest point is the important one to watch. But, it will, nevertheless, be observed that from port to port the conditions are quite variable with each individual furnace.

It would, of course, be possible to operate at a slightly higher pressure to ensure a positive pressure all the way along the bath from port to port. But this cannot be done with open-hearth furnaces, for example, so long as front wall conditions remain as they are. The state has not yet been reached where design and maintenance of doors and jambs are such that they always close tightly, thereby preventing flame leakage to the outside. Any such leakage of this intense flame is dangerous to refractories, and one is bound to seek a compromise—viz., reduced pressure conditions. Care must, therefore, be exercised on open-hearth furnaces, and on most furnaces this compromise must be effected, very often so much so that very far from ideal conditions result, conditions which are nevertheless essential for efficient heat transfer. In order to achieve optimum conditions, water cooling is necessary for doors, arches and jambs to ensure tightly fitting surfaces. This requires a good water circulating system, if possible solely for this purpose. How many plants yet have it?

How good it is to see the shop, which, on coming down the stage, looks dark, with no visible apertures round the

furnace doors, and yet with the recorders showing at least 0.080 in. w.g. roof pressure. And how depressing, on the other hand, to view a row of furnaces where one can examine through the door and the jamb, and very often even between the door and arch, the inside of the chamber. This is frequently the kind of job which has to be tackled and explains why, with open-hearth furnaces, it is sometimes more difficult to reap the full benefits of furnace pressure control than it is with other furnaces.

Leaving open-hearth furnaces for the moment consider the glass melting tank furnace. Here is a type of furnace with which the optimum conditions can more nearly be achieved, and where it can be clearly seen that balancing is necessary, not merely to check air infiltration but also to control the sojourn of the gas particles, or duration of their passage, between port and port ("stay time").

At first, the direction of flow is determined by the port design. On issuing from the port a particle of the gas still has kinetic energy which it loses rapidly as it flows into the laboratory, or combustion chamber. It has been explained above that this particle can maintain its direction until it is influenced by a sufficiently stronger force to overcome its residual energy. As soon as it becomes controlled by the chimney suction its speed increases up to the outlet port. Consequently, the magnitude of this suction force will determine, just as much as the original energy imparted to it by the port design, how long the gas particle will remain between the ports. Now this particle of gas has on its passage to mix with air (sometimes already in the port), ignite, reach its utmost intensity of combustion, deposit its heat at the right spot, and depart through the exit port. This is actually what should take place. Unfortunately, if there is no control over the balance of these forces, as time goes on, the ports will erode and become wider, thereby diminishing the mixing of the gas with air and, of course, its velocity. It has now less chance of igniting than before, and, because of its reduced velocity, is the more quickly influenced by the suction force. With reversing furnaces especially, as the ports wear, this suction force increases so that the condition is aggravated. It is small wonder that the fuel consumption increases and one hears of "ageing effect."

This, surely, is evidence that the suction force has more influence than just that of checking air infiltration.

It has been established for a long time that with producer gas a period of 2.4 secs. is required for a gas particle to deposit its heat after mixing. Figures have been established for various other fuels, and these figures are quite definite. Therefore, these periods at



Fig. 3.—Open-hearth furnace pressure regulator, showing winch and manual control handwheel.

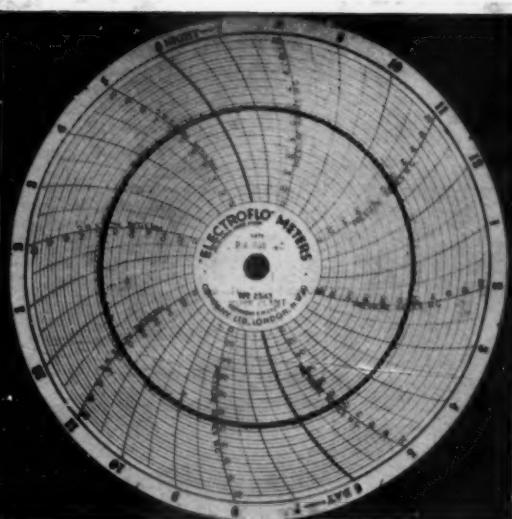


Fig. 4.—Pressure record taken on glass tank furnace with automatic control.

least must be spent by the gas particles between the ports. On open-hearth furnaces this means with a distance of 70 ft. between ports a maximum velocity of the gas particle of, say, 30 ft. per sec. But on a glass tank, having about 20 ft. port-to-port distance, this means a velocity of about 8 ft. per sec. only.

Now, it has been seen how necessary it is to control the suction so as to maintain an optimum furnace pressure and how critical is the establishment of this balance in the case of an open-hearth furnace. But with the glass tank one can see that, if at best the ports maintain their size, the amount of suction will determine the sojourn of the gas particle between the ports. It will determine whether the particle shall take the shortest path from port to port, or whether the particle shall only be influenced by it when it has more or less lost its initial impetus.

Between these two extremes, one has to find the right value of the suction force to deal not only with the problem of infiltration but to establish the correct mean velocity from port to port—i.e., the factor determining the period spent by each gas particle in the combustion chamber. This can be done quite successfully by observing the flame. Fortunately, with glass tank furnaces one is not worried by poor wall conditions as with an open-hearth furnace, having to deal with what is more or less a completely closed chamber. The furnace pressure may, therefore, be raised well above the value at which infiltration ceases and reach the optimum required for conditions of combustion. From practical experience it has been found to be of the order of 0.130 in. to 0.150 in. w.g. measured at the roof. Under such conditions it has been established on more than one tank that "ageing" as such did not occur after one campaign. This has been borne out in actual indisputable fact with no other furnace alteration than that of applying proper furnace pressure control.

All the above arguments apply, of course, to any type of annealing, reheating or normalising furnace. It is rather unfortunate that during the soaking period, when the fuel volume can be gradually reduced, the force



Fig. 5.—Pressure regulator on town's gas-fired heat-treatment furnace.

causing the discharge of the waste gases is now augmented by the extra heat owing to the increased buoyancy effect, and, therefore, if it is not deliberately reduced air infiltration will be greater than ever and, of course, at a time when it will be most detrimental to the material undergoing treatment. It is not quite so easy to reduce this suction force by the right amount at the right time, but a furnace-pressure recorder will be a guide, while a regulator will automatically make the correct adjustment.

From the foregoing one might not perhaps expect to achieve the gains theoretically possible; but, in practice, fuel savings up to 30% are quite feasible. One has only to make a thorough survey with the aid of furnace-pressure recorders to bring to light normal errors in operation and other shortcomings.

It should have been made evident that unconsidered use of the term "suction" and of the means of creating it by fans, exhausters and chimney stacks is far from being warranted owing to its immense influence. It is preferable and very much wiser to think in terms of furnace "pressure," employing the suction solely as a means to an end. Of course, the main effort must always lie in furnace and port design to achieve intimate mixing and proper flame direction. But it has been hoped to show by the above that neglect of furnace pressure can, without doubt, easily defeat all that well-designed burners are trying to establish. On the other hand, maintenance of the correct furnace pressure can, up to a point, improve conditions brought about by poorly designed burners or ports by securing optimum conditions of heat transfer.

How, then, does one set out to achieve it?

First, examine the furnace and decide where the pressure tapping may best be placed to measure truly static conditions. Usually, at the centre of the crown between the ports will be best. If there is a double crown, it will be necessary to use the side wall, well up and away

from any flame throw. Then, make sure that the size of the tapping is big enough, $1\frac{1}{2}$ in. diameter at least. Use piping with a bore of at least 1 in. diameter for short distances, and $1\frac{1}{2}$ in. diameter for distances above 20 ft., and make sure that the piping is absolutely leak-tight. Recorders only may be employed to start with ensuring that they are sufficiently sensitive to record changes of a few thousandths of an inch water gauge. These will provide a true picture of what is happening. Now try to establish the correct pressure at the hearth. Do not rely on "sting-out" alone since its visibility varies with the quality of combustion. A handful of dust thrown as a cloud by the door will provide a better indication. If the dust is drawn into the furnace, the suction is still too great, and the furnace pressure should be increased. Now examine the combustion conditions and see whether they can be improved by further increasing the pressure in the furnace. With high-temperature furnaces—e.g., melting furnaces, the tests should be made very carefully, proceeding step by step.

It will then be possible to determine how far control of the furnace pressure is practicable with the means available—e.g., damper, etc., and, having determined this optimum pressure, to proceed to automatic pressure control. This will ensure that the standard which has been established will be maintained, and that the benefits one is seeking are achieved. Finally, when considering installing automatic control obtain the services of the manufacturer's engineer to check your results, and make use of the experience he has gained on other installations.

Once the nature of the problem has been established, the simplest approach to its solution should be adopted, as, otherwise, complication may ultimately defeat the purpose one has in view. Furnace pressure, once understood, can be tackled in a very simple and straightforward manner, and its control will materially assist in achieving real results in a continuously correctly-balanced furnace. Always start your investigations with furnace pressure as the first step for it will facilitate analysis of all the other variables. Do not interfere with furnace design until you have first watched the behaviour of the furnace under stabilised conditions. In short, take first things first.

Philips Research Reports

A NEW issue of the above reports has just been published which contains four technical papers of physical and chemical interest. In the first paper F. L. H. M. Stumpers treats the problem of a rectangular noise spectrum applied to a valve with a non-linear current-voltage characteristic. J. L. Meijering and M. J. Druyvesteyn continue their researches into the hardening of metals, such as Ag and Cu with an admixture of Mg or Al, by internal oxidation. Consideration is given to the influence of oxidation on mechanical properties, creep, recrystallisation and brittleness. T. H. Oddie and J. L. Salpeter have developed a design method for chokes, carrying A.C., to enable the most economical dimensions to be found for any given electrical characteristics. A. J. Dekker and W. Ch. van Geel deal with the porous and amorphous layer of aluminium oxide, obtained electrolytically, which by oxidation in boric acid, may partly be changed into a crystalline layer.

It contains 80 pages and is admirably produced and illustrated. Copies can be obtained from the Publications Dept., Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C. 2. The annual subscription for six issues is 26s., single copies 6s. each post free.

Some Crack Detection Methods

By Horace Manley, B.Sc.

Many non-destructive methods have been developed and applied for the detection of internal flaws in ingots, forgings, castings and other metal products, and in this article a brief review is given of some of the methods more generally used.

Crack Detection

THE manufacturer of metal products and the foundryman are naturally concerned with pin holes and cracks either on the surface of their ingots, castings and machined products, or deep inside them. To detect internal flaws such irregularities as piping, pin holes, cracks, segregation and inclusions, there are but two techniques available commercially: radiography, using X- or gamma-rays, and ultrasonics, which is normally used as a Radar beam. The latter, which is the more sensitive of the two, will not detect surface and near surface cracks with the equipment as used at present. There are, fortunately, a variety of methods for surface crack detection, only two of these, however, are satisfactory, the others being inconsistent and unreliable or quite insensitive.

In engineering practice, where working tolerances predominate, the most desirable non-destructive testing equipment would either detect faults above a pre-set minimum size or clearly show, or allow judgment on, faults too small to be of any importance in the job on hand. This idea of tolerances is difficult to apply in crack detection, but it can be brought into some of the methods, fluorescent for example, to give a rough equivalent of a "go"—"no go" gauge.

Magnetic Method

The magnetic method of crack detection applies to all alloys which can be magnetised by induction, in effect all irons and steels, other than stainless, and high-nickel alloys. The idea is to inductively magnetise the sample, spread over it some fine iron dust or powder and observe the pattern. In a magnetised metal a crack gives rise to free magnetic poles on either side of the gap and these poles strongly alter the local magnetic field. When the crack is perpendicular to the field the magnetic anomaly is quite considerable near the crack and the iron powder crowds around these free poles, making the crack visually obvious. The method is most sensitive to cracks perpendicular to the magnetic field and to detect the parallel faults the specimen must be magnetised as nearly as possible at right angles to the first test.

The methods of inducing magnetism into the tested products have followed the same historical course as the academic methods to obtain high magnetic field strengths. The earliest method was to place the test specimen between the poles of a permanent magnet. Alnico and Alcomax were not then discovered and the resultant sensitivity of the apparatus was poor, for the magnetic intensity was never high. Electro-magnetic methods are now used and quite apart from the higher field strengths available are very much more flexible to use. At first coil windings and solenoids were used, and

still are for hollow goods, generally with a bar of soft iron placed inside.

Wherever possible the modern practice is to pass an electric current directly through the sample. The resistance of a large piece of metal is small and the current is high even for a very low voltage. An old D.C. plating generator serves as a good source of current. The currents used are as high as 5,000 amperes in the Electroflux apparatus; the Germans⁴ used 50 to 100 ampere turns at Siemen's and other works, whereas British practice is to rarely exceed 20 ampere turns, depending on the changes in cross-section of the sample and the metal involved.

The method normally used is to pour liquid over the metal surface while the electric current is on and observe the pattern in good illumination. The liquid is often paraffin oil with iron dust or powder suspended in it. The German "Periflux" apparatus uses very pure carbonyl iron powder in oil. The amount of powder in solution should be neither too much nor too little, since there is an optimum concentration for the best visual contrast. There is an added degree of flexibility in using the "Electroflux" type in that alternating current, travelling on the surface skin of the metal will detect surface cracks, whereas direct current will also show up cracks as much as $\frac{1}{4}$ in. below the surface.

There have been two further recent developments whose advantages, and troubles, are not fully known. One is the Russian method of obtaining permanent records.⁶ A rapid drying collodion liquid is used with crocus powder suspended in it. When this film is pulled off a permanent record can be kept, if desired, rather reminiscent of files of sulphur print etches. The other novel idea is the American "Magnaglo" which should combine the advantages of this and the fluorescent techniques.

The magnetic method is standard practice in advanced firms and the literature^{3, 4, 5} is extensive and critical. It is accepted as a reproducible and satisfactory test and there is a provisional standard test in the United States.

Fluorescent Method

When a liquid or paste is washed over a clean surface it penetrates into any holes and cracks. There are many old and simple techniques relying on the fact that recleaning the surface will normally still leave these crevices filled with paste or solution which are then visually obvious due to some dye or colouring substance in the liquid. The French chalk in paraffin oil and its improvements¹¹ the red lead¹ and the acid-etch techniques are all used for large cracks. The acid-etch is particularly good since it provides its own matte surface as a good contrast, but it cannot be used on finished products. By

and large, these methods have the same faults as railway wheel-tapping and bell-ringing tests. At best they will detect only large cracks and are rather crude and generally unsatisfactory.

The fluorescent technique is an improvement of this idea. A fluorescent chemical is dissolved in an organic solvent washed over the cleaned surface, and then washed off. Sometimes a further wash is applied to the surface to provide good contrast. When the surface is dry the liquid in the cracks tends to bulge over the surface due to surface tension and similar effects. The casting or machined product is observed under ultraviolet light (so-called "black light") when large cracks will appear to glow greenish-blue and even quite small ones will be seen to glint and flash.

The method is often good but still needs some improvising. It must be operated in a dark room, the liquids are often unpleasant smelling (carbon tetrachloride is commonly used as the solvent), three different washes are needed for some methods and the operator must be well protected from direct ultra-violet light which gives eyeball pains similar to welders "flash." The American "Zyglo"^{8, 10} and the English "Hyglo"⁹ are rather similar, but the latter uses electrical heating of the sample to dry it.

The solutions used may stain the metal but this applies to almost any crack detector and can be overcome. There is the interesting possibility¹² of arranging "limits" for crack size detected by setting the work at a definite distance from the observer. Intelligent unskilled girls can soon be trained to do the job well.

Other Surface Methods

In concluding the consideration of methods of detecting surface flaws, two further electrical methods, applicable to non-magnetic materials will be briefly discussed. The eddy current technique¹⁵ has been applied to most non-ferrous metals but as a complementary to the magnetic method for steels it is at once more complicated, less direct and not so satisfactory.

The basic idea is to listen to the change in the note, heard in a pair of earphones, of an electrical oscillating circuit as an inductance coil approaches the surface of the specimen. The change in the note is due to the eddy currents induced into the metal by the inductance coil. This distortion of the note is a measure of the soundness of the specimen, for cracks perpendicular to the eddy currents greatly reduce the currents by increasing the electrical resistance. As for the magnetic methods, cracks parallel to the eddy currents will not be detected, and so the coil must be moved to at least one other position as nearly at right angles as possible. The method is indirect and as used at present insensitive, since a small change in pitch in a high frequency note is not readily noticed by the human ear. There is obvious scope for improvement and the technique may become really useful. It certainly has the advantage that it can be applied to most alloys.

There is also the direct resistance method, such as the Metroflux², but it does not seem likely that this will become really sensitive, since the extra resistance due to a small crack is not readily detectable and the surface must be well polished.

Having given a brief survey of the methods for surface crack detection there remain the two very valuable ways of determining internal flaws, the radiographic and the ultrasonic techniques. Both of them depend on modern

scientific apparatus and cannot be easily used by non-technical personnel. Most of the previous methods can be worked by intelligent unskilled operators, women are probably best for the fluorescent tests and men for the electrical ones, for nearly every man has a crude understanding of electricity and magnetism. These indirect internal methods, however, need some skill in interpretation of the results and an understanding of modern physics both to keep the apparatus working and in repair and to use it to its fullest capabilities.

Radiography

The radiographic technique is very good, but is restricted in use chiefly by its high cost. It is invaluable for the inspection of welds¹⁴ and in foundries for checking new types of castings and forgings. No other method is possible in these two directions and most large foundries have some sort of X-ray equipment. In these large works the early detection of faults makes it economic to use X-rays by the saving of the cost of machining and later operations on faulty material.

The principle of X-ray technique is that X-rays are absorbed in passing through metals in proportion to the density of matter present. They affect photographic plates and films to give negatives similar to normal light photography. Places of segregation or cracks and holes show up in the film since more or less of the X-ray beam is observed in transmission than by the neighbouring normal metal. Hence this variation of X-ray intensity is shown up in the negative and the flaw detected. A variation of less than 1 or 2% in density is rarely noticeable and cracks must be in the plane of the beam.

The interpretation, taking and development of X-ray films needs care and experience. There are several ways blotches and dark lines can appear on a radiograph and be mistaken for faults in the ingot. Production managers do not always see the humour in cutting a steel ingot for suspected porosity when it is found to be perfect and the imagined fault on the film a stain in developing.

The operator must be protected from the X-rays and Potter Bucky grids or screens used to prevent secondary radiation. The film should be close to the metal to cut down the exposure time and prevent image distortion. The film is usually sensitised on both sides and of a fine grain suitable for enlarging.

For light alloys such as aluminium a 200 kv. tube is satisfactory but for steels of a foot or so thickness the highest possible voltage is needed. As an indication, a four-hour exposure necessary with a 1 mv. (million volt) tube may be cut to about four minutes at 2 mv. Further, the life of X-ray tubes is never very long and a series of long exposures prove costly in tube-life.

These high-voltage X-ray sets weigh up to two tons complete with accessories. They are quite mobile, however, and balanced so that they can be inclined and positioned by small electric motors. The whole apparatus is run about, or moved by crane, around the foundry.

Gamma rays¹⁶ are sometimes used. They need long exposure times since the source, radium sulphate in a platinum capsule is never strong but it is more penetrating, compared with say a 200 kv. X-ray set. Usually a collection of ingots are arranged in a circle with the capsule at the centre and the whole radiographed together (each one on a separate film, of course).

The use of a fluorescent screen enables a great speeding-up and is ideal for continuous inspection where it can be arranged. Where the film would normally be, a glass

screen, impregnated with platinocyanide or other substance, is placed and the image seen greenish yellow somewhat similar to a cathode-ray tube picture. It is much quicker but less sensitive, and normally there is no permanent record, although photographs may be taken just as one does with cathode-ray tubes.

As stated above, radiography is very valuable in large scale welding, foundry and forging work, but at present its wider use by small firms may be considered uneconomic.

Ultrasonics

The use of ultrasonics for internal fault finding in ingots and billets is continuously increasing in modern works. The equipment is not very expensive and only a little more complicated than a cathode-ray tube. The number of articles published^{18, 19, 20, 21} on its limitations and uses is now very great and indicates widespread activity in its use.

Ultrasonics are sound waves of such high frequency that they are inaudible to humans. They are readily transmitted by metals and liquids but also very easily reflected at air-to-metal surfaces. A beam is reflected by a very thin air film indeed and cracks can be detected 100 times as fine as by radiography. The sound waves generated by piezo electric oscillators in the most commonly used equipment (made by Henry Hughes over here and by Brush and Sperry in America). Due to the exceptionally good reflection at air/metal surfaces lanoline oil, tin amalgam or water must be used to give good contact between the oscillator and the metal.

A radar pulse of oscillations is sent out by the transmitter into the ingot. The pulse is reflected from the far end of the ingot and picked up by the receiver, which is also a piezo electric crystal, placed quite close to the transmitter. If there are any cracks in the path they will reflect part of the beam. These reflected waves, having less distance to travel, reach the receiver before those from the far end.

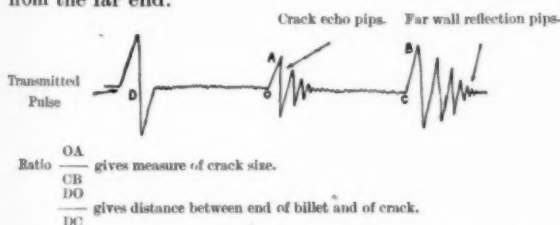


Fig. 1.—An example of sound waves on an ultrasonic viewer screen.

All these pulses are observed on a cathode ray tube which will look like Fig. 1. The distance between the reflected crack-echo and near wall reflections gives the depths of the crack below the surface, and the height of the pip an idea of the size of the crack. Determination of the echo-pip with the transmitter at two different places on the ingot surface gives the crack position to within a $\frac{1}{4}$ in. inside a 12-foot ingot. The technique is very similar to radar.

There is also absorption and scattering of the beam by segregation which can be detected by experienced operators and distinguished from porosity and cracks. Incidentally slag and oxide inclusions give more transmission than usual although non-detectable unless large.

The surface must be smooth and is ground, if necessary by a portable grinder. Scale may be allowed if it is continuous and adherent. Normally the quartz crystal

is inside a wedge-shaped probe and to ensure coupling to the metal an oil film or tin amalgam contact is essential. The far surface should be parallel for good results. In the case of curved ingots, special curved probes are used which are satisfactory if a standard curvature is met (i.e., the same moulds always used). Unless the curvature matching is good much of the beam power is lost.

The frequency used varies from 1-5 mcs. depending on the metal, ingot length and type of flaw. Faults close to the surface (within $\frac{1}{4}$ in. or so) cannot be detected because the echo pip is continuous with the transmitted pulse and so billets less than an inch thick are not examined. If necessary, porosity and crack faults may be distinguished by varying the frequency—this will be useful in porous metals such as self-oiling bearings. This is partly connected with the fact that unless the wavelength of the ultrasonics is less than the crack size, diffraction effects occur around the edges of the fault. At a frequency of 1 mcs. the wavelength will be $\frac{1}{2}$ in., which will be the limit of cracks detectable, as the frequency increases smaller cracks are noticeable, but transmission troubles prevent oscillations at greater than 5 mcs. being used. The apparatus is light and portable and takes only about 100 watts at 230 volts A.C. and so can be plugged into any light socket. (The smaller X-ray unit takes 1 kw. and extra for the vacuum pump and setting motors). The sensitivity is largely independent of frequency.

Faults must be perpendicular to the beam. This will be so with random small cracks, some of which will be detected, but it is useless looking with the beam set parallel to the suspected pipe. Scattered segregation on a large scale gives bad transmission and may be detected.

There are at least two methods suitable for the continuous inspection of strip. The Germans used a very good magnetostriction oscillator arrangement for lamination detection in war production strip. Incidentally, rolled-out bubbles are non-detectable by radiography. The ultrasonics beam is sent through the metal, using running water as a contact and detected by a suspension of aluminium powder in Xylol contained in a transparent plastic trough. With strong illumination the laminations are seen in the powder pattern. Normally all the small aluminum flakes set themselves parallel to the ultrasonic beam. Where the beam has been reflected by a lamination fault the particles are randomly orientated and easily seen as a pattern against their neighbours which are all set in one direction, perpendicular to the beam.

An earlier method used in the United States was a piezo electric oscillator modulated at 100 cycles so that it was audible in a pair of ear-phones and the faults were noticeable by a change in note or using a discharge lamp with a trip relay circuit. There was also a method of marking one side of the strip parallel to the lamination automatically as it was detected.

A flaw only 0.001 in. thick may be detected but the crystal must be set at critical distance above the strip, generally obtained by spring loaded rollers. (Radio men will recognise this as a case of matching impedances.

When the crystal is a height $\frac{\lambda}{2}$ above the surface the transmission is a maximum and at $\frac{\lambda}{4}$ a minimum where λ = about 1.4 mm. for water).

Ultrasonics in different forms, is widely used in small scale melting. It will efficiently degas melts with large density disparities such as lead-iron alloys; in grain refining while heat-treating; for thickness estimations in awkward positions and grain size detection (larger crystals give less transmission). Water and oil may tend to rust some surfaces or leave a deposit but it is unimportant since all tests are carried out at an earlier stage of production to save costs on working useless scrap.

The attached bibliography, though short, gives at least one reference to each method mentioned.

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Statistical Summary of the Mineral Industry of the British Empire and Foreign Countries

The first "Statistical Summary of the Mineral Industry of the British Empire and Foreign Countries" to be issued since 1939 has just been published and gives figures for each of the years 1938 to 1944. It will be recalled that previous issues of this standard work of reference covered periods of three years only. In the new issue it has been possible to incorporate statistics which, during the war years, had been strictly confidential; they are now made available to the public in concise form in a single volume covering a period of seven years. As data for 1945 were not entirely available at the time of going to press a further volume including the years 1945 to 1947 will be published at the end of the present year.

This issue contains 380 pages and gives statistics of the production, imports and exports of over 50 minerals and metals. In the case of copper, lead, tin and zinc, tables are included showing the production of ore in terms of metal in addition to smelter production. The section on coal, which occupies 27 pages, deals also with coke, briquettes and the chief coal by-products, whilst that on petroleum (40 pages) is concerned with crude petroleum, natural gasoline, natural gas, asphalt, oil shale and the chief refinery products, i.e., motor spirit, kerosene, gas oil, fuel oil, etc. The iron and steel section (25 pages) gives the world's production of iron ore, pig iron including ferro-alloys, and steel; in addition, further tables are included sub-dividing these into various categories.

The import and export tables refer not only to the crude minerals and metals, but to the chief semi-manufactures and in many cases to the principal chemicals and their derivatives. Copies may be obtained from the Imperial Institute, South Kensington, S.W. 7, from His Majesty's Stationery Office, or through any bookseller, price £1 1s. 0d. (£1 1s. 6d. post free).

An Electrode Holder that Won't Break

THE holder with which an electric welder grips his electrode must be an efficient di-electric to give him perfect protection against shocks, but it must obviously have other qualities. It must for instance, be non-hygroscopic so that its electrical resistance is not impaired by moisture and humidity, and it must be adequately heat proof. Welding appliances come in for rough usage and brittle insulation must not be used. It should not be so heavy as to cause unnecessary fatigue, but a designer who aims at economy in weight must not effect it at the expense of the metal mechanism; lightness must come from his choice of insulation.



The Mascol patent welder electrode holder.

Here is a case where densified wood laminates and resin bonded paper tubes provide ideal materials; they are light, tough, non-hygroscopic, and excellent di-electrics. The makers of Quasi arc welders are producing the Mascol patent welder electrode holder with a solid block of Permali as the hand-guard upon which the holder is built up. A hollow bronze bar of generous dimensions is keyed through the block, and the electrode, inserted into a hole drilled in the side of the bar, is gripped by a non-revolving internal plunger which is operated by twisting the handle; the action, in fact, is that of a neat hand-vice. The bronze bar above the hand-guard is protected by a light alloy hood with an inner sheath made of mounded asbestos $\frac{1}{8}$ in. thick; the handgrip below the guard is a bakelised paper tube of $1\frac{1}{4}$ in. diameter which is keyed to the inner turn-screw-terminal with a Permali peg.

The Mascol cathode holder is a comfortable and well-balanced tool which weighs only $1\frac{1}{4}$ lb. of which 8 oz. is accounted for by insulation. It is a satisfactory example of the intelligent use of suitable materials in design.

Ball and Roller Bearings

British Timken, Ltd., recently sought permission to extend further their Duston Factory. It is now announced that the Ministry of Supply has approved this new extension scheme, and the building licence has been received from the Ministry of Works which will enable work on the extension to commence.

Powder Metallurgy Notes

By J. Heuberger (Stockholm)

The production of components by the powder metallurgy method is sometimes necessary, for many parts, however, it provides an alternative method of production which may be more economical in materials and labour costs than that usually adopted. The method is advantageous in some applications when high purity of the material is sought. The notes given in this article will assist towards a better appreciation of the process.

POWDER metallurgy is the technique of manufacturing metallic objects from metal powders or metal sponge without, or with only partial, melting of the material. At one time it was proposed to name it "metal ceramics" in order to emphasise the similarity between powder metallurgy and ceramic methods. A further indication of the close relationship between the two methods may be found in a recent lecture by Professor J. Arvid Hedvall on the silicate chemistry work of his school at Göteborg in which he described his field as "oxide metallurgy" or "metallurgy without metals."

The term powder metallurgy covers also the science of the macro- and microstructural changes which occur in powder metallurgy processes. Powder metallurgy is therefore a separate branch of metallurgy with many relations to the general physics and chemistry of metals.

In the manufacture of articles by powder metallurgy metal powders are compacted, in most cases without admixtures, by punch and die combinations to form objects which are given their final strength by a heat-treatment either simultaneously with the pressing or subsequent to it; in the former case the method is described as hot-pressing, and in the latter case the heat-treatment is called sintering. This heat-treatment is carried out at a temperature below the melting point of the metal powder, or the main portion of it, but structural changes such as recrystallisation, grain growth, etc., take place at relatively high rates. The green pressing is held together largely by molecular surface forces between the powder particles. It has a metallographically discontinuous structure, which during sintering passes into a more or less homogeneous structure, the original powder particles being more or less completely united by the growth of a crystal lattice through the points or areas of contact.

It requires careful investigation in each case to decide to what extent the impurities on the particle surfaces take part in the sintering process as boundary material. The substances which form the boundary layers of the particles are generally "impurities" and have so far been added intentionally only in very few cases. They are important not only chemically and physically, but even more so from the point of view of their distribution in the powder. Identical metal powders with equal contents of the same "impurity" may differ fundamentally in their sintering behaviour owing to the distribution of the impurity. It may, therefore, be assumed that the study of these particle boundary materials would throw also fresh light on the classical problem of grain-boundary material and its influence upon the properties of the metal.

Research in powder metallurgy will probably contribute many new points of view upon old metallurgical

problems, because the sintered product exhibits many structural phenomena on a larger scale, though possibly more crudely. Particle boundary substances again will probably reveal close connections between powder metallurgy and ceramics. On the industrial side transitions will probably appear between powder metallurgy and plastic resin bodies containing fillers.

During sintering, the green pressing undergoes deformations, partly by shrinkage due to surface tension forces which increase with decreasing particle size, and partly by expansion which is caused mainly by gases evolved in the compact with increasing temperature. These two opposing kinds of deformation probably occur in practice always together. The magnitude of the dimensional change during sintering which results from the difference between shrinkage and expansion depends upon the nature and history of the metal powder, upon its purity, upon absorbed and adsorbed gaseous and liquid films, upon the shape and surface properties of the particles, upon the sieve analysis of the powder, upon the compacting pressure used, and lastly upon the rate of heating and the furnace atmosphere during sintering. Unequal pressure distribution in the green pressing, which can never be completely avoided, or uneven particle size distribution, which occurs for example during filling of the die, may result in the predominance of shrinkage or expansion in different parts of the sintered compact, which is consequently distorted. Similar anisotropy effects explain also the differences between the properties of the skin of a sintered compact which may be technically valuable in many ways, and its interior.

Owing to these deformations it is often necessary to subject the sintered compact to a coining operation which may also increase its density, hardness, etc., and which may be combined with heat-treating, tempering and other such processes. The structural changes which take place form a highly interesting field for research.

In designing press tools for powder metallurgy work, it is necessary to allow for the escape of gases entrapped by compacting of the powder without causing segregation or removal of the very fine size fractions. These considerations are not important when compacting is carried out in a vacuum.

Sintering and other heat-treatments are generally performed in a protective gas, that is, in an atmosphere which is neutral or reducing in relation to the constituents of the compact. Owing to the high surface activity of metal powders, "neutral" gases also have a considerable effect upon the sintering process. More or less severe gas adsorption and rapid desorption or release of gases in other ways may produce almost explosive effects upon the final structure of the compact.

Sintering atmospheres—vacuum sintering is rarely used owing to practical difficulties—are obtained by introducing gases or vapours, for instance also light

(Translated from "Festskrift tillägnad J. Arvid Hedvall," Göteborg, 1948, pp. 241-248, by Mr. R. A. Hetzig, Powder Metallurgy, Ltd.)

metal vapours, into the sintering furnace or by packing the green pressing in a gas evolving material. Sometimes the metal powder may also be mixed with such a substance before compacting. Every powder metallurgist will have discovered that frequently quite slight changes in the protective atmosphere affect the sintering result, and that in particular it is difficult to control traces of moisture which may derive from the gases on the furnace walls or the compact. This effect may be either detrimental or favourable for the sintering reaction—if it is permitted to use the term reaction in connection with sintering processes. It will in most cases be difficult to decide whether the traces of moisture affect the metal or the particle boundary material. Here powder metallurgy presents many analogies with the pioneering work of Hedvall's school on the effect of "inactive" gases upon powder reactions.

With most metals, the green pressing possesses a high degree of strength. When the particles are compacted, the particles become mechanically interlinked through surface irregularities. If the particles are not excessively hard, the elastic limit is exceeded at the points of contact during pressing, and the particles are deformed in such a way that the original points of contact become more or less definitely parallel surfaces, the molecular adhesion forces between which produce the cohesion of the compact. The pressing process will then differ according to whether the surface films on the particles are disrupted or not. Finally, friction between particles during pressing which is generally relatively rapid may produce such high temperatures at points of inter-particle contact that sintering or welding occurs at these points. If the word welding is used it does not necessarily imply that a liquid phase has been formed.

In this connection, reference may be made to numerous discussions as to whether oxide-reduced, carbonyl, or atomised powders are preferable for powder metallurgy work. (Sponge powder made by the reduction of oxides has not the spherical shape and the more or less smooth surface of powders made by the other two processes). This question can only be decided in each particular case. It is certain that with sponge powders mechanical interlocking is more important for the cohesion of pressings, whilst compacts from powders with spherical shape are held together rather by molecular forces at plastically deformed contact surfaces. Some light is thrown upon these problems by metallising processes in which metal coatings are built up from atomised molten metal, generally in the form of under-cooled metal droplets.

The mechanical working of metal powder during pressing generally produces a hardening of the metal so that the green pressing is as a rule considerably harder than the sintered compact. According to the method of powder production, a considerable amount of energy, internal stresses, and lattice deformations are stored in the individual powder particles before pressing. The relaxation of these lattice disturbances, which are concentrated in particular at the points of contact in the pressing, may well be the chief factor responsible for metallic sintering. Die wall friction accounts for the differing structure of the surface of the sintered compact compared with its interior.

This does not mean, however, that the sintered compact is free from stresses. Even if this were so at sintering temperature, new stresses are produced during cooling owing to anisotropy in the direction of pressing

and differences between the interior and the surface of the pressing. Generally speaking, it is somewhat difficult to correlate the different processing factors with the physical properties of the sintered products, because the sintering temperature should really be taken as a basis and not the measured temperature, which is, as a rule, considerably lower.

The behaviour of the powder before use, its stability and ageing properties, its flow properties and tendency to segregate in the die, and its compacting and sintering properties depend upon its history, its chemical purity, shape, particle size distribution (sieve analysis), surface activity, particle porosity, etc. Methods of powder production are therefore frequently included in the field of powder metallurgy. Metal powders can be produced in many different ways, for example by precipitation from solutions, electrolytic deposition, decomposition of gases, comminution of molten or solid metal. Although the powder metallurgist cannot claim to know the entire field of powder production, he must thoroughly understand the history of the powder with which he is working, because only then will it be possible to appreciate and control the different phenomena which occur during sintering. In this respect the powder metallurgist is fully justified in asking the powder manufacturer for data which may extend to the virgin state of the metal and even to the ore from which it is derived.

Sintered compacts can be prepared from the powder of a single metal, from alloy powders, from mixtures of powders of different metals which may alloy during sintering by diffusion, but also from mixtures of metal powders which alloy only most incompletely (e.g., copper and lead) and finally from mixtures of metals and non-metals. As far as non-metals are concerned, the field of powder metallurgy was extended beyond the limit of its name before its name had even been coined.

The term sintering is frequently misunderstood, and there are also many different views on it. In practice, sintering nowadays generally means the heat-treatment of a green pressing accompanied by considerable consolidation at a temperature below the melting point of the powder, or in the case of a mixture of several metals, with or without non-metals, at a temperature below the melting points of the major portion of the mixture, so that the pressing does not become plastic but retains the essential dimensional ratios of its geometrical shape, apart from shrinkage and expansion.

In several cases, notably the manufacture of articles from metals with very high melting points, powder metallurgy methods were applied originally through necessity, because it was at that time not economically possible to obtain high temperatures on a technical scale (e.g., the production of platinum sheet from sponge and the manufacture of electric lamp filaments). Even now, when very high melting temperatures can be reached owing to progress in furnace construction, the powder metallurgy method is frequently preferred not only because it may give certain desirable metal structures which are only exceptionally or not at all possible with casting, but also because the article produced by powder metallurgy has a greater purity. High melting point metals—namely, very easily take up impurities from the crucibles or furnaces, a danger which is avoided at the considerably lower sintering temperatures.

Some articles can be made by powder metallurgy which cannot be made by the classical methods at all—

e.g., porous bodies having a controlled porosity as regards number, size and shape of the pores, can be prepared by suitable choice of particle size and size distribution, compacting pressure and sintering conditions. Such porous sintered products are important as filters (e.g., sintered nickel filters for concentrated alkalis) and for bearings in which latter case the pores are filled with a lubricant. These porous sintered metals show that powder metallurgy can give industry quite new materials with properties which can be adjusted to designs within wide limits. Powder metallurgy increases not only the number of technically valuable metals but also their diversity, as it is not confined to the limits set by Gibbs' phase rule.

Materials which can be made by powder metallurgy but not by casting include primarily combinations of materials which do not alloy or which cannot be prepared

by casting owing to large differences in specific gravity or melting point and vapour pressure. Examples of such materials are combinations of metal and graphite (copper-graphite brushes), metal and carbides (for cutting tools, etc.), metal and diamond (for lapping discs), or of metals with widely differing melting points such as tungsten and silver (contacts), where a highly porous compact is prepared from the higher melting point metal powder and is then impregnated with a melt of the other metal.

Several powder metallurgy processes have by now been in use for a long time, but only in the last few decades has an effort been made to co-ordinate data and experiences gained from work in different fields. Powder metallurgy, however, will only become a science when order has been brought into our knowledge and understanding of the processes.

Ministry of Supply Apprenticeship Scheme to be extended

FURTHER opportunities for graduate engineers to gain practical experience, before specialising, will be afforded under the new Ministry of Supply plan to recruit 20 graduate engineers a year. In conjunction with the graduate programme the Ministry will take on also 20 student apprentices each year, who will work for twelve months at a Ministry establishment prior to their taking a full-time university course.

To be accepted as a graduate apprentice the candidate must be more than 21 years of age, but not over 24, with a Degree or Diploma in Engineering awarded by a recognised University or College after a full-time course. The training they will receive has been designed to fit them for any type of engineering appointment, whether it be with the Ministry or with a commercial organisation.

Graduate apprentices will be instructed in fitting, turning and machining, erecting, smithing, pattern-making, foundrywork and drawing office practice. In addition to this manual type of work they will learn the methods, organisation and planning employed in a modern engineering shop. This type of experience is calculated to give the graduate an appreciation of craft skill, and a first-hand knowledge of industrial working conditions, both of which are essential for managerial work.

Graduates will serve for at least two years, with the option of remaining for a further year. At the completion of their two or three years term they will be given every opportunity to join the Engineers' Pool, which by virtue of the Ministry's vast undertakings in the technical field offers the young engineer a variety of factories and establishments which include atomic energy, research and development in many different spheres, production such as at the Royal Ordnance Factories, and inspection of stores and materials.

Student apprentices must be under 19 years of age and have secured a Higher School Certificate or equivalent, with mathematics and physics as main subjects. The apprenticeship is offered on condition that at the end of a year the candidate will enter for a full-time University Degree or Diploma Course. Today it is acknowledged that a year's practical experience before entering a university is of great advantage to the student. In the event of an original student apprentice returning as a graduate apprentice he would be obliged to do only 12 months in a Ministry establishment before applying for entry to the Pool.

Both grades of apprentices will work according to the normal hours applying in the various shops or sections where they may be employed, and residential centres will be available for those who have to live away from home. Applications can be submitted at any time, but not later than August 31 if a candidate desires to commence training in October of the same year.

Locomotive Works Practice

A CONSIDERABLE step forward in British locomotive engineering has been made by the adoption of limits and fits standards for the great majority of components in all types of locomotive engines—steam, diesel and electric. These standards, which are given in a book entitled "Limits and Fits for Locomotive Work," recently published by the Locomotive Manufacturers' Association of Great Britain, 82, Victoria-street, London, S.W.1, have been adopted by the whole British locomotive-building industry.

The degree of interchangeability now offered to users is such as to simplify substantially running-shed maintenance replacements, shop overhauls, and the ordering and assembly of spare parts, particularly where a user has locomotives of two or three different makes.

Built up partly on the "hole basis" and partly on the shaft basis to meet the special problems of locomotive manufacture, the new standard practice is listed under 14 different headings, viz., regulator and boiler mountings; cylinders, steam chests and covers; inside cylinders, steam chests and covers; crossheads and slidebars; piston and rod, piston valve and spindle, and valve crosshead; Walschaerts motion details; Stephenson's motion details; connecting rods, coupling rods; wheels, axles and crankpins; axleboxes and guides; brake and spring gear; forms and dimensions of rivets; mild steel sections and bars; and adequate illustrations and tables are provided to make the practice self-explanatory.

In drawing up these standards, all known practices, recommendations and specifications were considered by the sub-committee of the L.M.A. which was charged with the work; and the result has been a thoroughly practical set of limits and fits, not out of line with many existing individual requirements, and which can easily form the basis of world-wide locomotive specifications, with consequent benefit to users of all makes and types of locomotives.

Cinema Roof in Aluminium Alloys

THE use of aluminium alloys as structural materials has made considerable headway since the war and many excellent examples have been given of the employment of aluminium for structural work in buildings. Not the least interesting of recent applications are those associated with the roof of a cinema recently built at Rye, especially since it is the first cinema to be licensed for construction since the war. The roof of this cinema has a 60-ft. span and carries a plaster ceiling on Hy-rib reinforcement and a covering of "Big Six" asbestos-cement corrugated sheets. Although the trusses are of shallow construction, as is often the case in cinema construction to suit architectural requirements in the ceiling construction, the weight of the heaviest truss is only approximately 7 to 7½ cwt. The "Hy-rib" ceiling is fixed to the aluminium alloy ceiling framing to provide a support for a ¾ in. plaster ceiling. Walkways are also provided in the roof for access to the lighting coves, again being supplied in aluminium alloy, while all supports for ducting for ventilating plant are also in aluminium alloy.

A feature of the construction is that the roof trusses are fixed to a reinforced concrete beam which forms the top of the main auditorium walls, and bracing is provided between the roof trusses, the purlins and this reinforced concrete beam. This provides a longitudinal-braced girder giving lateral stability to the top of these walls by transmitting all wind loads on these walls to the ends of the building.



Courtesy of Almin Ltd.

Roof joints in aluminium alloy as used in the Regent Cinema, Rye. The work was designed and erected by Structural and Mechanical Development Engineers Ltd., Slough, Bucks.

The erection has been carried out very easily and, therefore, economically, due to the light weight of the roof trusses, and all purlins and ceiling framing being light enough to be manhandled into position. It has only been necessary, therefore, to use a 5-inch diameter scaffold pole for hoisting these trusses into position, with the result that erection was completed in approximately 16 days by 4 men.

Staff Changes and Appointments

DR. NORMAN SWINDELLS, M.A., Ph.D., has been appointed chief metallurgist to the Birmingham Works of McKechnie Brothers, Ltd., Metal Manufacturers, of Rotton Park Street, Birmingham, 16.

MR. N. F. ASTBURY, previously with Messrs. Joseph Sankey & Sons, Ltd., is now Director of Research at the G. K. N. Research Laboratories, Manor Works, Ettingshall, Wolverhampton, Staffs.

MR. F. WARDROBE has retired from his position as chief engineer of William Jessop and Sons, Ltd., Sheffield, but remains a director of the company and as consultant to the company on plant and engineering developments.

MR. E. H. BALL has been appointed to the Board of the Metropolitan-Vickers Electrical Co., Ltd., as from 4th May, 1948.

The following appointments in the Sales Division have been made by the British Aluminium Co., Ltd. :—

MR. H. H. CUNDELL has been appointed sales manager, responsible for sales department ; MR. A. W. LANGHAM, who temporarily undertook responsibility for sales and sales planning departments, following the appointment of Mr. E. A. Langham to India last year, will continue to be responsible for sales planning department, with the title of sales planning manager as before ; MR. E. E. SPILLET has been appointed development manager in place of Mr. Cundell ; and MR. P. S. W. SWABEY has been appointed assistant development manager in place of Mr. Spillett.

MR. W. D. MARSH, until recently of Murex Welding Processes, Ltd., has taken up an appointment as a research metallurgist with Messrs. Hadfields, Ltd.

MR. E. G. WILLOCK, formerly blast furnace superintendent of the Indian Iron and Steel Co., Ltd., has now returned to England. He has taken a position on the metallurgical staff of Messrs. John Miles & Partner (London), Ltd.

MR. D. C. G. LEES, has been appointed metallurgist to the Aluminium Development Association and will take up his new duties in September.

MR. P. WRIGHT, M.C., formerly assistant to the iron and steel works manager of the Workington branch of The United Steel Companies, Ltd., is now general manager at the Ministry of Supply factory, Monk Bridge, Leeds.

MR. NORMAN PARKINSON, M.Sc., A.R.I.C., has resigned his post at the Nelson Research Laboratories of the English Electric Co., Ltd., Stafford, to take up an appointment as Electrometallurgist at the Tin Research Institute, Fraser Road, Greenford, Middlesex.

MR. H. G. WARRINGTON, F.I.M., has left Almin, Ltd., and has taken up a position as Metallurgical Engineer with Dominion Magnesium, Ltd., Suite 406, 67 Yonge Street, Toronto 1, Canada.

MR. T. W. HAYES has been appointed by A. C. Wickman, as Export Manager under the direction of Mr. J. W. Buchanan, Export Director.

MR. JAMES DURRANS, Chairman and Managing Director of James Durrans and Sons, Ltd., Penistone, has been appointed a Justice of the Peace for the West Riding of Yorkshire.

MR. T. W. RUFFLE has resigned his position as metallurgist at Leyland Motors, Ltd., to take up a post as metallurgist with the Motor Industry Research Association.

Magnesium Alloy Scrap

The Availability of Helium

By A. G. Arend

UNLESS some new processes have been developed, no means are at present open in this country for supplying large quantities of this important gas, at least at moderate cost, and conditions here are quite different from those in the United States. Whereas helium is obtained in this country only as a by-product from atmospheric gas separation to the extent of 1 part in 200,000 parts of air, the amount present in Texas natural gas has been known to reach from 1 up to 7%. The extent to which it is present in natural gas available in other parts of the world has not been divulged in detail.

Apart from American sources being the largest for the actual raw material, another important feature is the great expansion of synthetics and synthetic rubber plants, where experience had already been gained in the use of monoethanolamine and diethylene glycol, besides other industrial organic chemical operations. With a combination of these two advantages it is easy to understand how efforts were made to accommodate the fabrication of their magnesium output.

Most of the gas was at first used for purely welding purposes, where the benefit of operating without the use of fluxing agents was of outstanding importance. This was turned to account in the welding of various parts of the wings, fuselage, and other sections of modern aircraft, where without fluxes corrosion troubles were reduced to a minimum as a consequence. The same remarks do not apply to scrap-cutting where the idea is to reclaim rapidly as much magnesium as possible. Ignition of the magnesium, however, is prevented where helium is used as the blanket during these cutting processes. Prior to the war, the cost of the gas was so considerable as to rule it out, except for the treatment of some respiratory illnesses, anaesthetics, deep-diving purposes, etc., although it had been tried as a substitute for hydrogen for the inflation of dirigibles. As a consequence of the expansion of magnesium and synthetics as a result of the war, the costs of production in 1944 were claimed to have been reduced to 1 cent per cubic foot with gas of 98% purity. This met the requirements of aircraft welders, and to-day correspondingly reduces the costs of cutting the scrap metal.

The Improved Recovery Process

Briefly, the recovery of helium from natural gas comprises scrubbing it with mixtures of monoethanolamine and diethylene glycol solutions at a pressure of approximately 650 lb. per square foot. The water vapour present, together with carbon dioxide, which amounts to about 0.5% of the volume, and any little hydrogen sulphide which periodically appears, are all removed by this treatment. Advantage is taken of improved instruments to check-up on the extent of action of the scrubbers, which automatically record the reduction of both carbon dioxide and hydrogen sulphide in the continuous manner. The instrument for recording

the latter gas was evolved in 1943 (and which automatically performs an average of 6 determinations per minute) consists of a photometer of the ultra-violet type. The principle involved is based on the phenomenon of light absorption according to a specific wavelength for each particular gas.

The recovery process operates as a continuous cycle, since heat evolves the impurities from the reagents, which are then returned for re-use. Mechanical losses alone necessitate additions of fresh monoethanolamine and diethylene glycol solutions. The purified natural gas is then progressively cooled to -185°C . using counter-current heat exchangers, and under a pressure of some 300 lb./sq. in., all constituents are liquefied, with the exception of helium and a little nitrogen. By so doing, helium of 50% purity is obtained, and could have been raised to a much greater purity in the one stage but for the fact that it is soluble in liquefied natural gas, and with the higher pressures required for complete purification, losses by this solubility would thereby be sustained.

For this reason, the work is carried out in two cycles, and the foregoing process is repeated on the 50% product, but at a pressure of 2,500 lb./sq. in., which raises it to 98% purity, in which condition it is discharged into containers for industrial use.

Cyclic Nature of the Different Stages

The process is noteworthy in respect of the cyclic nature of the different stages, firstly, by the continuous return of the reagents which have removed the water vapour, carbon dioxide, and hydrogen sulphide, and secondly, by the use of the liquid nitrogen which is utilised in the heat-exchangers mentioned. The natural gas cycle and nitrogen refrigeration cycle are kept separate, and the nitrogen separated is compressed to some 60 lb./sq. in., and expanded through the engine which latter runs a form of hydraulic brake.

Heat energy is thereby removed from the nitrogen, and with a temperature some 85°C . lower than that of the inlet pressure gas, the nitrogen which flows to the engine is cooled by this exhaust. The helium discharged to the containers from the second cycle is not subjected to any further pressure. In comparing this process with that of the almost infinitesimal recovery of helium present in air, in which methods the gas is recovered at the top of the column, the output from natural gas is so very great as to rule out all alternative systems from consideration. What little helium has so far been recovered from radioactive materials is likewise too small to be considered for industrial purposes, at least, at present. From the metallurgical aspect, the large output of this gas has resulted in numerous small improvements in welding torch tips and associated equipment to utilise it to best advantage, and future developments in other welding activities can be expected from this wide use of helium.

¹Metallurgia, 32, 1943, 200-202.

Sir William Murray Morrison

A Pioneer of the Aluminium Industry

SIR W. MURRAY MORRISON, whose death at the age of 74 occurred in London recently, was a pioneer of the aluminium industry in Great Britain. More than that, he was a man to whom the industry throughout the world owes a great debt, for it was largely owing to his optimism, ability and clear judgment that aluminium ceased to be a rarity and became one of the world's leading metals.

Trained as an engineer at Edinburgh University and at the Glasgow Technical College, where he studied under Lord Kelvin, he went to Foyers in 1895, where the newly formed British Aluminium Company were installing the first large hydro-electric plant in Great Britain, and so began his lifelong association with the Company. Foyers had been set up to work the new Hall-Héroult process for making aluminium by electrolysis, and Murray Morrison, in the absence of technical knowledge and experience of the process, had to develop and improve it in every way possible. In this he was assisted by Lord Kelvin, acting as a Consultant. Success at Foyers led to subsequent hydro-electric developments at Kinlochleven (1907) and Lochaber (1930), with associated electrolytic reduction factories. As a result, the annual output of metal from the Company's highland factories increased from 300 tons at Foyers to a present-day total of 30,000 tons. These developments brought to isolated Highland districts a great measure of prosperity; and the Acts of Parliament which brought them into being were largely Sir Murray's work from the technical and business angles.

The original alumina factory at Larne became quite inadequate for the Company's growing needs, and Murray Morrison, who was appointed General Manager in 1910 (becoming Managing Director in 1927 and Vice-Chairman in 1934), was responsible for the construction of new alumina factories at Burntisland (1918) and at Newport, Mon. (1938). He was responsible, too, for developing the rolling mills at Milton, in Staffordshire (first set up in 1894) and at Warrington (1912) and for the great plant established at Falkirk during the last war.

In addition to these developments, his Company established reduction and fabricating plants in Norway and India and, in association with other firms, in Australia, China and elsewhere. Companies for operating bauxite mines were formed in France, British Guiana and the Gold Coast, and the parent Company has to-day over 20 subsidiary and associated companies. With this growth of the industry, Sir Murray became well known internationally and acquired a very considerable reputation both as technician and as business man.

He was knighted in 1943, and made a Commander of the Order of St. Olav of Norway in 1933. He was a member of the Institution of Civil Engineers, a member (and past member of Council) of the Institution of Electrical Engineers, a Fellow of the Institute of Physics, a past member of Council and Vice-President of the Faraday Society and of the Institute of Metals (whose Fellowship and Platinum Medal were awarded to him in 1942), and a Vice-Chairman of the British Non-Ferrous Metals Research Association.

His charming personality endeared him to his many friends who will remember him as a delightful man whether at work or in recreation.

Mr. Sydney Smith

WITH deep regret we have to announce the death of MR. SYDNEY SMITH, managing director of The Wellman Smith Owen Engineering Corporation, Ltd., who passed away on 30th May, 1948, after a period of failing health. Mr. Smith had been connected with the Wellman Companies for many years, and little more than twelve months ago succeeded his brother, the late Mr. James Foster-Smith in the chief executive position as Managing Director. His loss will be mourned by a large circle of friends and business associates.

Recent Retirements

MR. HERBERT ASHBRIDGE, who for over twenty years has been Works Manager with The Churchill Machine Tool Co., Ltd., has retired. He served his apprenticeship with Hulse & Co., Ltd. Apart from a short period with The Cleveland Automatic Co., for nearly 50 years he has been associated first with Charles Churchill & Co., Ltd., and later with his present firm, the well-known makers of precision grinding machines.

MR. WALTER SYDNEY SPICER of 30, Knowle Lane, Sheffield 11, has retired after 47 years' service with Messrs. Hadfields, Ltd., of East Hecla Works, Sheffield. Joining the Company at the age of 17, at the Hecla Works in Newhall Road, he was chiefly employed in the examination and testing of raw materials, refractories, etc., used for steelmaking processes, being closely attached to the late Sir Robert Hadfield during his formative years. In 1941 he was transferred to East Hecla Works as Chief Buyer and Stores Superintendent, and in 1946 was appointed a Local Director.

He performed valuable work during the war period on National and Local Committees concerned with the preparation of specifications, the purchasing and the distribution of raw materials and refractories, and has been for many years a member of the Iron and Steel Institute and of the Sheffield Engineering and Metallurgical Association.

On his retirement, he was presented by the Directors with a raw hide travelling case, and by his colleagues with a wristlet watch and a radio receiving set, together with a mystery present from his own personal staff. A most kindly and genial personality, ever ready to assist younger colleagues from his wide experience, he will be greatly missed, and carries into his retirement the good wishes of every member of the Staff of Messrs. Hadfields, Ltd.

The Institute of Welding

At the Annual General Meeting of the Institute, on 30th June, the election of the following Honorary Officers for 1948-49 was announced:—

President: J. H. Paterson, D.Sc., F.R.I.C.

Vice-President: O. V. S. Bulleid, M.I.Mech.E.

Honorary Treasurer: W. E. Harriss.

A vote of thanks to the out-going President, Mr. J. L. Adam, C.B.E., M.I.N.A., was moved by Sir Stanley Goodall, K.C.B., and carried by acclamation. The Council presented to Mr. Adam a replica of his photograph, specially taken for preservation in the Council Room of the Institute.

Reviews of Current Literature

Electrolytic Polishing

THIS is the first of two volumes on the subject by a recognised authority and deals with the electrolytic polishing of aluminium, magnesium and their alloys. Dr. P. A. Jacquet indeed has, in recent years, become one of the pioneers in a field which he has made specially his own, and in which many new vistas of hope and promise in metallurgical research have been opened up, as are more definitely indicated below. The work is based not only on a considerable amount of his own investigation, but also on a fairly exhaustive survey of the great mass of accumulated literature and patents. It is perhaps a little curious that in this survey, including most aspects of metallic surface phenomena, the name of Beilby should be missing, although in the author list the Beilby layer is mentioned on page 132, but then the most painstaking searcher cannot pretend to include everybody.

The book comprises four parts: (1) principal methods and technique; (2) applications to physico-chemical studies; (3) use in micrography; and (4) industrial applications. These are preceded by Forewords contributed by Clyde Williams, Director of the Battelle Memorial Institute, U.S.A., and G. Chaudron, Sorbonne professor, and Director of the Vitry Chem. Lab., Nat. Centre of Scientific Research in France. The former pays a graceful tribute to the value and originality of the author's work both in scientific fundamentals and in practical applications; and the latter gives a brief historical review of these studies beginning about 1930.

As a matter of fact, the exact date is 1929, when the electrolytic polishing of metals and alloys in its original form was discovered by H. Figour and P. A. Jacquet in the laboratories of Soc. Le Matériel Téléphonique. It has since been modified and improved, and its amazing developments in America, France and England, have been repeatedly recorded in the technical press, both in regard to industrial large-scale operation and, what is possibly of still greater interest, its application in metallurgical and general scientific research, especially micrographical study. It is now applicable to a wide range of metals and alloys, and in Vol. II some account will be given of electrolytic polishing of other than the light metals.

For the metallurgist the use of this method in micrography will probably be the most interesting section. As Prof. Chaudron reminds us, it was in connection with the micrographic examination of the structure of electrolytic copper, about 1931, that it occurred to Jacquet to test the possibilities of anodic solution in place of the usual polishing methods; and, as he also reminds us, the surface structure of metals throws much light on their internal conformation, on friction, fatigue, deformation, etc.—a light which is intensified by the new electrolytic technique as used for micrographical research. Here the use of low c.d. made possible by an electrolyte of high perchloric acid concentration, which are among the characteristic features of the improved Jacquet method, has proved particularly valuable in obtaining the right kind of surface for study of heterogeneous alloys.

In this section (III) practically all the commercially known aluminium alloys—binary, ternary, and quaternary—are included, as well as those known under

various trade names: Y Alloy, Anticorodal, Silumin, and of course duralumin. Particular attention is directed to alloys of aluminium-copper, and aluminium-magnesium. The micrography of aluminium is dealt with in detail in Chap. I of this section and includes a fine collection of micrographs relating to both the pure and impure metal. It is hardly necessary to point out that all electrolytic polishing methods show up, very clearly, inclusions and insoluble constituents and also certain defects in the cast metal, as well as crystal structure, and deformation and re-crystallisation, in the case of ultra-pure aluminium. A chapter is devoted to examination of welds. Various methods of electrolytic polishing are compared at the end of this section, and more thoroughly in Part IV.

In this last part of the book the Brytal and Alzak processes are examined in detail, and some account given of industrial applications of electrolytic polishing. In his general conclusions, the author can well claim that the relative ease with which smooth bright surfaces can be obtained on metals and solid solutions, without any change in structure or chemical constitution, by these new methods, makes them invaluable in physico-chemical studies hitherto nearly, if not quite, impossible. For aluminium research such surfaces have been already utilised in connection with studies of diffusion, X-ray diffraction and electronics generally, and with measurements of electrolytic dissolution potentials.

Although the value of the work from a micrographical standpoint has been stressed there are doubtless many other matters of equal interest and importance, such for example as the use of the new technique in the study of corrosion—in which it is particularly valuable—and in the measure of micro-hardness, both of which are fully treated in Part II. Electrolytic polishing has permitted a much more reliable study of the hardness of aluminium as a function of applied load, since the readings have not been systematically falsified by the disturbing effects of mechanical polishing; and among other advantages Meyer's law is valid. A useful summary of the work of Schutz, Hanemann and Bernhardt is included.

The book in its 350 pages of 4to well bound and printed on paper of excellent quality, contains a veritable mine of information for the metallurgist and physical chemist, with a bibliography of about 200 references and generously beautified with illustrations. It should be invaluable to both the research worker and to the engineer.

Le Polissage Electrolytique des Surfaces Métalliques et ses Applications, par P. A. Jacquet, Ingenieur Chimiste I.C.P. Docteur de l'Université de Paris, etc. Tome I. Aluminium, Magnésium, Alliages légers. Saint-Germain-en-Laye (S. et O.): Editions Metaux, 1948. (Price not stated.)

Werkstoffe Aluminium und Seine Anodische Oxydation

THE electrolytic oxidation of aluminium had been studied in a desultory manner for many years before the full potentialities thereof for corrosion protection and surface finishing were realised. The work in England, 25 years ago, of Bengough and Stuart where chromic acid electrolytes provided the necessary impetus for intensive research from which the present world-wide anodising industry developed.

Patents, technical and scientific publications on various aspects of the anodic oxidation of aluminium and its alloys are now counted in hundreds, but authoritative books on the subject are rare, and, indeed, there is still no modern work in English. The present book was, therefore, received by the reviewer with somewhat mixed feelings: of pleasure that a comprehensive treatise should now be available, tempered with regret that still no British work exists.

Dr. Max Schenk, the author of the present book is an acknowledged authority on anodic oxidation; he invented and developed the well-known Ematal process, which produces anodic coatings on aluminium and some of its alloys closely resembling vitreous enamel in appearance, such effects being obtained by using electrolytes containing salts of titanium or zirconium.

The book is bulky (1,042 pages) and may be divided into two approximately equal sections. The first section deals with the mechanical, physical, chemical and electro-chemical properties of aluminium and its alloys, including chapters on metallography, methods of joining, heat-treatment and corrosion. Whenever possible, the author attempts to relate both metallographic structure and design structure with the anodising characteristics. For example, both heat-treatment and bonding are discussed from the angle of their influence on the subsequent anodising behaviour of the parts.

The second section is an extremely detailed and comprehensive treatise on anodic oxidation, covering physical, chemical and mechanical properties of anodic oxide coatings. Technical processes of anodic oxidation, after-treatments, defects, installation and choice of plant, control and testing methods for both coatings and solutions are fully treated. A valuable chapter is contributed on cost calculations and international patents are listed, apparently complete for Swiss patents, but with some notable omissions in the list of U.S. and British patents. Adequate and, from incomplete checks, accurate indexes complete the book.

Binding, printing, quality of the paper and the copious well-reproduced illustrations are all excellent, but it is possible that these sumptuous features will be considered by many to be insufficient recompense for the exceptionally high price of the book (160/- at present exchange rate). In the opinion of the reviewer, the author and publishers would be well advised with subsequent editions to issue the book in two separate parts, thus giving the opportunity to Praktikers (*sic*) interested chiefly in anodising as such to purchase for half the present price the section with which they are mainly concerned.

References to the original literature are voluminous and, where checked, accurate, but many readers will be irritated by the system adopted of collecting full references into bibliographies at the end of each chapter with mention only of authors' names in the text, which are then found to be not in alphabetical order in the bibliographies.

The lists of alloys commencing on page 62, contain many obsolete specifications and some notable omissions were noted in both the U.S. and the British lists.

The extremely short comment on page 296 on the now generally accepted Wagner theory of the mechanism of oxidation and anodising could with advantage be enlarged and it is also a matter of regret that the author has omitted any mention of the important work of Tomashov and Tyukina on the mechanism of sealing by dichromate solutions.

On page 953, the specific gravity of the anodic oxide coating for purposes of thickness calculations is given as 3.1, a value with which many will disagree, and, in addition, in many sections of the book there is a regrettable absence of a critical approach to the subject matter. Thus, the various Mylius tests (page 962 *et seq*) the Zurbriigg test and the D.V.L. corrosion test are all described in some detail, but the author does not mention that these tests have fallen into disrepute with most corrosion workers, since they give an entirely false idea of the relative merits in service of various materials. The fallacious results obtained by using hydrogen peroxide as an accelerator in corrosion tests have been discussed in the literature many times, and it is surprising that Dr. Schenk fails to introduce at least a passing reference to such criticisms.

In Table 113 (page 967) an excellent example is unwittingly given of the fallacy of using ill-conceived accelerated tests, since the weight losses after corrosion by acidified sodium chloride solutions of anodised pure aluminium, sealed by hot water and dichromate solution, are recorded as 21g./m.²/day and 116g./m.²/day, respectively; the author does not make the obvious comment on such results.

Apart from such criticisms, however, which are few when set against the background of the wide field so comprehensively surveyed, Dr. Schenk has written a valuable and dignified addition to the literature on aluminium and its alloys, the anodising section of the book filling a need which has long existed.

By M. Schenk. Published by A. Francke A.G. Berne, Switzerland (in German). Pp. 1042. Price 138 Swiss Francs.

Light Alloy Castings

THE light alloy foundries which turned out such large numbers of aluminium and magnesium alloy aircraft castings during the war, are now playing their part in the production of equipment for the post-war world. A recent publication issued by High-Duty Alloys, "Commercial Castings in Hiduminium," clearly demonstrates the change. The castings illustrated range from washing-machine components to "Dodgem" car bases and from parts for automatic looms to food handling equipment. That the aircraft industry is still a consumer of these alloys, for both civil and military purposes, is illustrated by the companion booklet, "Aircraft Castings in Hiduminium and Magnuminium." Both booklets are designed to show the size and type of castings which are being produced. Particulars of the various alloys and their application can also be obtained from Messrs. High Duty Alloys, Ltd., 89, Buckingham-avenue, Slough, Bucks.

Heat-Resisting Steels

To those concerned with the use of heat-resisting steels, the 44-page brochure, No. 473, recently published on this subject by Hadfields, Ltd., will be of interest. The composition and salient characteristics of "ERA H.R." Steels are listed, together with the appropriate physical and mechanical properties at room and elevated temperatures. Stress-temperature curves are given for a creep-rate of one-millionth per hour after 40 days under load. Mention is made of machining, forging and cold forming, and full particulars are given of the welding of these steels by the metallic-arc and oxy-acetylene methods. In applications where the conditions are not so severe as to justify the use of heat-resisting steels, a number of alternative grades are available.

MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS

METALLURGICAL

APPLICATIONS

TECHNIQUE

"FRANCE has discovered that when a country starts from scratch on atomic projects, the worst bottleneck is analytical chemistry." These are the words, recently quoted in a contemporary, of Leo Kowarski, the Scientific Director of the French Atomic Energy Commission. They are yet another indication of the way in which certain gaps in our scientific resources, gaps which have existed for many years, have only been spotlighted through the intense importance of recent developments in atomic research. Perhaps one can correlate recent activity in analytical fields in the United States of America with a similar discovery. We feel, however, that there is also a realisation in that country that the lack of analytical workers can prove an equally serious bottleneck in other fields, although its effects may not be so popularly realised. Scientists in many fields completely unconnected with atomic research have repeatedly emphasised in recent months the fundamental importance of the analytical chemist. In this country we have heard it said that it was only when atomic research projects got under way that the lack of properly trained analytical chemists was seriously recognised. France, the United States and this country, therefore, are all of one mind on this point. It is perhaps regrettable that almost certainly the analytical chemist will owe his rehabilitation in large part to this lack in the more spectacular field. But no matter how the realisation has come, it is clear that he is on the way to taking his proper place in the chemical world.

Group Separations in Inorganic Qualitative Analysis

Part I—Schemes Based on Sulphuretted Hydrogen

By Francis R. M. McDonnell and Cecil L. Wilson

Microchemistry Laboratory, Chemistry Department, The Queens University of Belfast.

(continued from page 117 June issue)

Hydroxides, Carbonates and Sulphates

Several schemes have been put forward for the analysis of the filtrate from Group II which depend largely on the properties of hydroxides, carbonates and sulphates. Purgotti¹⁵ who uses phosphorus pentasulphide instead of sulphuretted hydrogen for the precipitation of the Group II cations, treats the filtrate from this Group with sodium carbonate, hydroxide and hypochlorite. The subsequent separations are as shown in Table IX.

Three procedures have been tested by Komarovskii and Grœmukin¹⁶. In the first, shown in Table X, after the removal of hydrogen sulphide, calcium barium and strontium are removed as sulphates. The filtrate is

treated with sodium hydroxide and hydrogen peroxide, leaving aluminium, chromium and zinc in solution. The residue is redissolved, and iron and magnesium are precipitated as hydroxides, leaving nickel, cobalt and magnesium in solution.

In the second scheme, outlined in Table XI, aluminium, chromium and zinc are taken into solution as the first step. The residue is redissolved, and all cations but potassium are precipitated. These are then further subdivided into two major groups. The third scheme, shown in Table XII, is really a variation of this.

La Rosa¹⁷ also precipitates the sulphates of calcium, strontium and barium with ethanol and sulphuric acid, as shown in Table XIII. Subsequently, a precipitation is carried out with sodium or potassium hydroxide.

¹⁵ Purgotti, *Gazz.*, 1912, **42**, ii, 58; *B.C.A.*, 1912, **102**, ii, 984.

¹⁶ Komarovskii and Grœmukin, *J. Arp. Chem. (U.S.S.R.)*, 1931, **4**, 877; *C.A.*, 1932, **26**, 1873.

¹⁷ La Rosa, *Chimica*, 1939, **15**, 392; *C.A.*, 1940, **34**, 3611.

TABLE IX
To the filtrate from Group I add 1-5 g. P_2S_5 according to the amount of Group II metals present. Heat to about 60° C. with frequent shaking until a small portion gives no precipitate with H_2S .

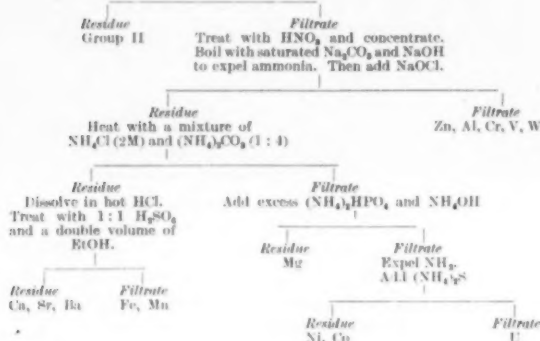


TABLE X.
To the filtrate from Group II, add H_2SO_4 and C_2H_5OH

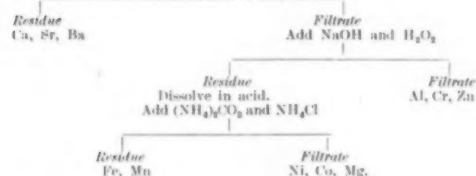
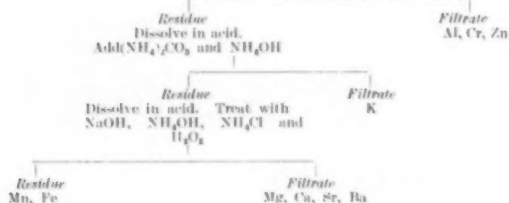


TABLE XI.
To the filtrate from Group II add $NaOH$, Na_2CO_3 and H_2O_2



In Petersen's scheme,¹⁸ the cations are subdivided into seven groups, each of which contains, at the most, two cations. The first step after the removal of hydrogen sulphide is the precipitation of barium and strontium with sulphuric acid (Table XIV). Aluminium is then removed as the soluble sodium salt. The residue is treated to dissolve all remaining cations but nickel and cobalt, and subdivision of this solution is achieved by sodium carbonate and hydroxide, sodium peroxide, and ammonium phosphate.

De Pauw¹⁹ has modified Petersen's scheme slightly by treating the solution, after removal of nickel and cobalt, with solid sodium carbonate and sodium hypochlorite. This has the effect of bringing zinc and chromium together. Bolin and Starik²⁰ criticise Petersen's scheme, and they suggest several improvements, including the use of sodium sulphate instead of sulphuric acid for the precipitation of the alkaline earth cations. Again, the use of sodium hypochlorite instead of sodium peroxide brings manganese into solution with chromium. With these, and other slight modifications, it is claimed that Petersen's scheme becomes very efficient.

An unusual modification of the classical scheme is proposed by Tarugi,²¹ who follows the classical procedure up to the precipitation of iron, aluminium and chromium with ammonia. He then precipitates cobalt, nickel and manganese as ferricyanides in dilute hydrochloric acid solution. The classical procedure is then reverted to, the only other deviation being the subsequent precipitation of zinc ferricyanide in acetic acid solution.

TABLE XII.
To the filtrate from Group II add $NaOH$, Na_2CO_3 , and H_2O_2

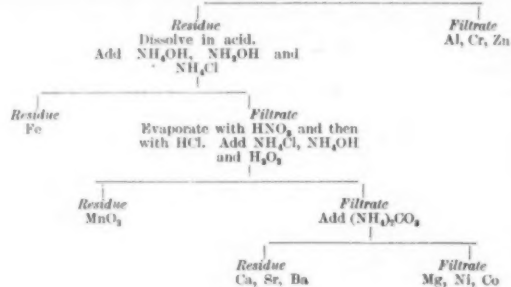
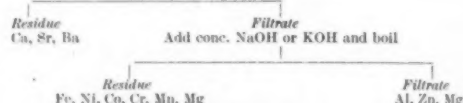


TABLE XIII.
To the filtrate from Group II add H_2SO_4 and make 40% ethanolic.



Oxalate Precipitation

At least two modifications of the classical scheme have been proposed which depend to some extent on the action of the oxalate ion as precipitant. Lucknow²² merely uses oxalic acid to subdivide the cations at the beginning of the analysis. After dissolution of the specimen in aqua regia, excess of boiling oxalic acid solution is added. Under these conditions, chromium, aluminium, tin, iron, antimony and arsenic remain in solution. Precipitate and filtrate are then analysed separately in the classical manner.

Charmandarjan²³ removes Groups I and II as usual. The filtrate is then tested for iron, ammonium and phosphate. Ammonium sulphate is then added (Table XV) to precipitate the alkaline earth sulphates. To this boiling suspended precipitate is added ammonium oxalate. This converts calcium and strontium sulphates to oxalates, leaving barium unaffected. The sulphate-oxalate residue is ignited, the oxalates being thus converted to oxides. The barium sulphate is unchanged. Dilute acid then takes the calcium and strontium into solution. The filtrate after the removal of the alkaline earth cations is separated by the use of barium hydroxide, sodium hydroxide and bromine, or hydrogen peroxide.

Organic Reagents

A number of schemes have been advanced in which the group separations remain for all practical purposes the same as in the classical scheme. However, subsequently little further separation of the groups is attempted, and organic reagents are used to identify the cations in the dissolved group precipitates. Schemes of this type have been devised by Winkley,

18 Petersen, *Z. anorg. Chem.*, 1910, **67**, 253; *B.C.A.*, 1910, **98**, ii, 654.

19 De Pauw, *Chem. Weekblad*, 1920, **17**, 191; *B.C.A.*, 1920, **118**, ii, 451.

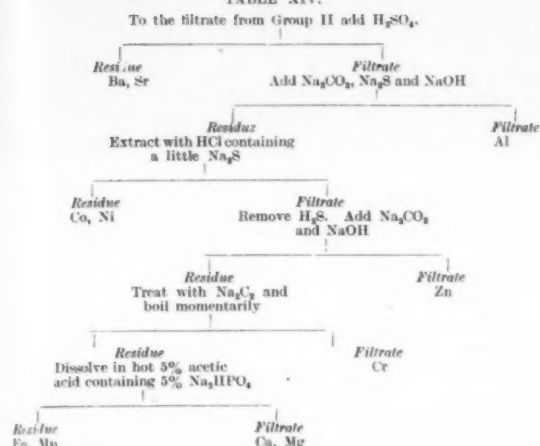
20 Bolin and Starik, *Z. anorg. Chem.*, 1918, **103**, 69; *B.C.A.*, 1918, **114**, ii, 324.

21 Tarugi, *Gazz.*, 1895, **25**, ii, 478; *B.C.A.*, 1896, **70**, ii, 391.

22 Lucknow, *Chem. Z.*, **10**, 763, 793; **11**, 5; *B.C.A.*, 1886, **50**, 922, 1897, **52**, 329.

23 Charmandarjan, *Z. anal. Chem.*, 1929, **79**, 90; *C.A.*, 1930, **24**, 1052.

TABLE XIV.

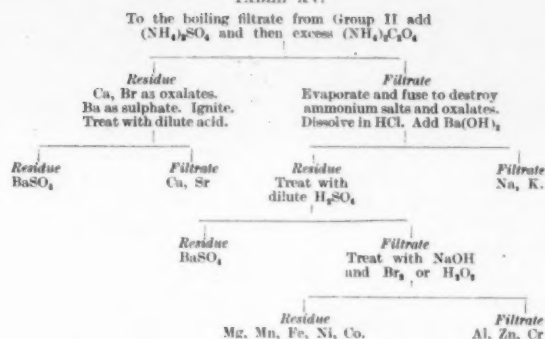


Yanowski and Hynes²⁴, Dobbins and Southern,²⁵ Cule-Davies²⁶ and van Nieuwenberg.²⁷ One defect of this type of procedure is that several cations are identified in the same solution, which often applies a limit, through interferences, to the number of confirmatory tests available for any given cation.

It should also be pointed out that a vast number of methods for resolution of the various group precipitates, and for removal of interfering anions, have been put forward. No attempt is made in this review to cover such modifications, but in particular attention has been

²⁴ Winkley, Yanowski and Hynes, *Mikrochem.*, 1937, **21**, 102.

TABLE XV.



paid by many workers to removal of the phosphate interference, and to methods of resolving Groups II and III of the classical procedure.

In addition to ordinary chemical separations, at least one method has been put forward which utilises inorganic chromatography for the analysis of the HCl , H_2S and $(\text{NH}_4)_2\text{S}$ groups, apparently with a certain amount of success.²⁸ Although the method has been little used in the past, it is possible that it will become of more value. Williams²⁹ has stated that with further investigation it might be possible to base a whole system of qualitative analysis on the principles of chromatography.

²⁵ Dobbins and Southern, *J. Chem. Educ.*, 1942, **19**, 479.

²⁶ Cule-Davies, *ibid.*, 1940, **17**, 231.

²⁷ van Nieuwenberg, *Mikrochem.*, 1931, **9**, 199.

²⁸ Schwab and Ghosh, *Angew. Chem.*, 1939, **52**, 666.

²⁹ Williams, "An Introduction to Chromatography, 1946.

Rapid Determination of Small Amounts of Silicon in Magnesium Alloys

By D. F. Phillips and S. E. Hermon

A method has recently been described for the gravimetric estimation of small amounts of silicon in aluminium alloys. This has been adapted to the satisfactory determination of the same element in magnesium alloys.

THE routine determination of silicon in magnesium alloys within the range 0.02–0.25% is normally carried out by dissolving the sample in brominated nitric acid, adding sulphuric acid and evaporating to fumes in order to dehydrate the silicic acid. The silica is then collected in a filter, ignited in a platinum crucible and weighed.

Disadvantages of the above procedure are the time and care required during the evaporation stage in order to avoid losses by spattering, and the violent bumping which occurs when redissolving the sulphuric acid cake preparatory to filtering.

For more precise determinations a similar procedure to the above is used, but perchloric acid replaces sulphuric acid as the dehydrating agent. By this means spattering is prevented, but perchloric acid is expensive and considered somewhat hazardous for routine analysis. The complete removal of perchlorates during final washing of the silica is also rather tedious.

Knowledge of silicon content of magnesium alloys is of vital importance to the foundry metallurgist as remelted process scrap is always liable to introduce contamination into virgin material. It was therefore found desirable to investigate analytical procedures with the object of reducing the time taken to determine silicon. It should be mentioned here that methods based on measurement of the light absorption of the blue silicomolybdate compound are in use for determining amounts of silicon not exceeding 0.02%. This upper limitation is imposed because of the impossibility of obtaining a direct solution by acids of silicon present in magnesium alloys in excess of this amount without resorting to fusion in alkaline carbonates.

In recent publications^{1,2} a rapid gravimetric method for silicon determinations in aluminium alloys has been described. In this method gelatine is used to flocculate the silica, thus avoiding the necessity for tedious evaporation to fumes. The authors investigated the described

procedure with reference to aluminium alloys, and were able to confirm the reliability and advantages claimed. It was, therefore, considered worth while investigating whether a similar procedure could be used for magnesium alloys containing from 0.02-0.25% silicon. The method now to be described has been found to give results in close agreement with those obtained using perchloric acid and/or sulphuric acid. The time required for a batch of 12 determinations is about 2½ hours as compared with 6-7 hours using the older sulphuric acid procedure.

Reagents Required

Brominated nitric acid:—1 volume saturated bromine water, 2 volumes nitric acid, S.G. 1.42. Make up freshly before use and cool well.

Sulphuric acid mixture:—6 volumes 1:1 sulphuric acid S.G. 1.84, 1 volume hydrogen peroxide, 20 vol.

Gelatine solution:—0.25% solution prepared from hot but not boiling water. Keep sterile by adding one pea-sized crystal of thymol per litre of solution.

Wash solution:—10 ml. 1:1 hydrochloric acid S.G. 1.19, 20 ml. 0.25% gelatine solution. Make up to 1 litre with water.

Procedure

Weigh a 2 g. sample into a 500 ml. conical beaker and add gradually 50 ml. brominated nitric acid. When the reaction is complete, wash down the sides of the beaker with distilled water and add 35 ml. sulphuric acid mixture. Evaporate to approximately 40 ml. volume. Cool slightly and wash round with 10-20 ml. distilled water. Add 40 ml. gelatine solution and two pulped accelerators. Stir vigorously with a glass rod. Stand for about three-quarters of an hour at room temperature. Filter through a Whatman 540 containing an accelerator pad. "Bobby" the beaker and wash the precipitate 10 times with wash solution. Dry and ignite at 1,000° C. Cool and weigh.

$\text{SiO}_2 \times 0.4672 = \text{Si}$.

Discussion

Table I shows results obtained using the gelatine method just described in comparison with those obtained by the perchloric acid and/or the sulphuric acid methods. In all cases the agreement is considered satisfactory.

The last column of Table I gives results from a series of tests in which no nitric acid was used in dissolving the alloy. The drillings were first covered with saturated bromine water, and solution of the alloy completed by addition of sulphuric acid mixture. Flocculation by means of gelatine was then carried out as above. In the majority of cases these results are lower than those obtained by the other three methods. They are included here because they appear to confirm that unless strongly oxidising conditions are maintained whilst dissolving magnesium alloys, slight losses of silicon may occur—probably as silane. This effect is very noticeable in the last sample shown in Table I which was taken from a melt of badly contaminated process scrap.

In most of the samples additional alloying constituents were present within the ranges given below.

Aluminium	2-14%
Zinc	0-0.75%
Manganese	0-0.30%
Copper	0-0.50%

BIBLIOGRAPHY.

- 1 R.I.O.S. Final Report No. 1589. A rapid method for the gravimetric determination of silicon with particular reference to aluminium alloys as practised in Materialprüfungsamt in Berlin.
- 2 Struss, W. Improved gravimetric determination of silicon in aluminium alloys, developed in Germany during the war. *Metallurgia*, 38 (May, 1948), 63.

TABLE I.—COMPARATIVE RESULTS OF SILICON DETERMINATION USING VARIOUS METHODS

Gelatine method % Si	Perchloric acid % Si	Sulphuric acid fuming % Si	Gelatine without nitric acid % Si
0.09	0.08	0.10	0.09
0.16	0.16	0.15	0.11
0.13	—	0.12	0.13
0.12 0.12	0.12	0.12	0.09
0.19	0.20	0.19	0.15
0.11	0.12	0.10	—
0.15	0.14	0.16	0.13 0.14
0.12	—	0.12	0.13
0.18	—	0.18	0.16
0.19	—	0.18	0.12
0.24	—	0.23	0.25
0.21	—	0.20	0.24
0.19	0.20	0.20	0.18
0.22	0.22	0.20	0.16 0.16
0.29	0.28	0.26	0.23 0.23
0.39	0.39 0.63	0.63 0.63	0.47 0.47

The authors wish to thank the directors of Messrs. High Duty Alloys, Ltd. in whose laboratories this work was carried out for permission to publish these results.

Instrument Companies Combine to form Hilger & Watts Ltd.

THE well-known instrument companies, E. R. Watts & Son, Ltd., and Adam Hilger, Ltd., are being formed into one Company, registered as Hilger & Watts, Ltd. Watts was founded in 1856 and has specialised in the manufacture of surveying and engineers' measuring instruments, while Hilgers, started in 1874, has built up a world reputation for instruments for research and industry. The ranges of the respective productions are complementary to each other, and the instruments developed by Hilger for chemical, biological and medical research will dovetail closely with the products of James Swift & Son, Ltd., microscope makers, who are a subsidiary of Watts.

The Board of Directors of the new Company is an amalgamation of the Boards of Hilgers and Watts, namely:—G. A. Whipple, M.A., M.I.E.E., chairman and managing director; F. Twyman, F.R.S., technical adviser; A. C. Menzies, D.Sc., controller of research; D. R. Stanley, controller of sales; V. W. H. Towns, technical controller; and R. H. Watts, assistant controller of sales.

A high proportion of the products of Hilger & Watts, Ltd., are for export, and the overseas sales will be mainly through Scientific Exports (Great Britain), Ltd., and, for engineers' measuring instruments, British Engineers' Small Tools and Equipment Co., Ltd.

Aluminium Wire and Cable Co. Ltd.

THE Aluminium Wire and Cable Co. Ltd., 10, Buckingham Place, London, S.W.1, announce that they have now transferred to their works at Swansea, the manufacturing facilities for aluminium and alloy wire and hot rolled rod previously operated by The British Aluminium Company Ltd. and Reynolds Light Alloys Ltd.

Sales of wire and rod made at Swansea will continue for the present to be handled by The British Aluminium Company Ltd., but will be taken over by the Aluminium Wire and Cable Co. Ltd. in a few months' time. The exact date will be announced later, but in the meantime, deliveries to customers against existing orders will not be affected.

METALLURGICAL DIGEST

Practical Method Developed for Plating on Magnesium

By H. K. de Long, *The Dow Chemical Co.*

A PROCESS of plating on magnesium by methods established for plating on other metals has been patented by the Dow Chemical Co. In order to remove and prevent the reformation of a hydroxide film the process consists of three parts: (1) a combination of mechanical and chemical cleaning; (2) zinc-coating by immersion; and (3) electroplating in the usual way.

Preliminary degreasing and pickling operations precede any mechanical grinding or buffing to prevent surface contamination being embedded or partially covered in the buffing.

Cleaning

The complete process consists of:—

- (a) Solvent degreasing.
- (b) Alkaline cleaning by soaking for 3–15 mins. in a high pH cleaner, such as the following, at 85–100° C.
Sodium carbonate, 3 oz.
Caustic soda, 2 oz.
Wetting agent, 0.05–0.1 oz.
Water to make one gallon.
(Proprietary alkaline cleaners as used for steel are satisfactory for this operation.)
- (b-1) Rinsing in running water.
- (c) Pickling (prior to buffing if metal is oxidised or has a chemical coating).

Castings are pickled for 1–3 mins. at 20°–30° C. in a 75–85% (by vol.) solution of phosphoric acid (H_3PO_4) in water.

Sheets, extrusions and forgings are pickled for 1–2 mins. at 20°–30° C. in the following aqueous solution.

20% (by vol.) glacial acetic acid.
5% (by weight) sodium nitrate.

Containers for these solutions may be of crockery or mild steel lined with rubber or synthetic materials. In addition, stainless steel is suitable for the former solution and pure aluminium for the latter.

(c-1) Cold rinsing followed by hot rinsing to assist drying.

(If black powder deposits, water streaks or general light smutting of the surface occur, the parts may be dipped in a caustic soda solution (8–12 oz./gal.) immediately after pickling and before rinsing. The caustic soda bath is preferably operated warm (60–85° C.).

(d) Polishing, by buffing or tumbling, where bright deposits are required.

(e) Solvent degreasing.

(f) Alkaline cleaning by soaking for 3–5 mins. at 85–100° C. in the following aqueous solution:—

8 oz./gal. (6%) tri-sodium phosphate ($Na_3PO_4 \cdot 12H_2O$).

An anodic clean for 10–20 sec. at 6 v. tends to de-plate any possible heavy metal deposits that might be formed in the soaking.

(f-1) Running water rinsing.

(g) Pickling for 15–60 sec. at 20°–30° C. in a 1% (by vol.) solution of hydrochloric acid.

Containers may be of crockery or mild steel coated with rubber or synthetic materials. Uncoated metal tanks may result in a loose immersion deposit on the work.

The above solution is satisfactory for magnesium alloys containing aluminium, but not, in general, for Dowmetal M (1.5% Mn) as a dark smut is sometimes left on the surface. For M alloy a 1% acetic acid solution should be used.

(g-1) Rinsing in cold running water.

N.B.—The pickles under (c) are intended for the removal of heavy oxide and chromate finishes whilst those under (g) are designed to serve as surface activators and will remove thin hydroxide coatings. The latter pickling time should be kept to a minimum consistent with removing all passive areas on the surface as indicated by a uniform overall etching.

Immersion Zinc Coating

The parts are immersed immediately, whilst wet from rinsing, for 3 mins. in the case of M alloy and 5 mins for aluminium containing alloys, in the following aqueous solution.

120 gm./litre tetra-sodium pyrophosphate ($Na_4P_2O_7$).

40 gm./litre zinc sulphate ($ZnSO_4 \cdot 7H_2O$).

10 gm./litre potassium fluoride (KF).

5 gm./litre potassium carbonate (K_2CO_3). pH 10.2–10.4.

The carbonate serves to adjust the pH value and more or less than the amount shown may be required as determined by pH measurements.

This bath must be made up with water relatively free from iron salts. Therefore, it is preferable to use distilled or de-ionized water. Good commercial grade chemicals which are low in heavy metal salts as impurities, such as iron or copper, can be used. The optimum time of treatment may vary slightly from one alloy to another but should not be less than 3 min. nor more than 7 min. Both a prolonged treatment and too short a treatment will result in inferior adhesion of subsequent electrodeposits.

Stainless steel is preferred as a tank material for holding this solution in production use. Mild steel should not be used. Rubber-lined steel, Monel, or nickel tanks may also be satisfactory. The heating coil, if steam is used for heating, should also be of stainless steel.

The zinc immersion bath should be prepared by first adding and dissolving the zinc sulphate in water at room temperature. The solution is then heated to 50–60° C. and the tetra-sodium pyrophosphate added. A fluffy precipitate will form which will dissolve after stirring for a few minutes. Once the precipitate is completely in solution the potassium fluoride is added and then the carbonate to adjust the pH. Rinse parts in cold running water, or spray rinse after zinc coating. Do not use a hot water rinse.

From *Materials and Methods*, May, 1948, 27, 5, pp. 63–65.

Copper Strike

Copper strike immediately in a copper cyanide-Rochelle salt bath operated at 45-50° C. and of the following composition:—

- 5.5 oz./gal. (41.3 gm./l) copper cyanide
- 6.8 oz./gal. (50.8 gm./l) sodium cyanide
- 4 oz./gal. (30.0 gm./l) sodium carbonate (soda ash)
- 6 oz./gal. (45.0 gm./l) Rochelle salts.
- 0.25 oz./gal. (1.9 gm./l) sodium thiosulphate (hypo)
- Free sodium cyanide—0.75 oz./gal. (5.6 gm./l) pH = 10.0-11.0 (preferably 10.0 to 10.5)

Electrical contact is made quickly and a low current density of 5 to 10 A./ft.² is applied for the first 2 to 3 min. After this 2-3-min. initial deposition the current density is increased to 15 to 20 A./ft.² and deposition continued for at least 5 min. Rinse in water. Do not hot-water rinse if preceding another plating operation.

Plating

Copper can be plated in heavier deposits by prolonging the plating time in the above bath, or by transferring the work to other alkaline-type cyanide or pyrophosphate baths. Proprietary bright copper plating baths are quite satisfactory for building up the copper plate thickness. Pyrophosphate bath tend to attack magnesium, and unless the parts are completely covered with copper from the strike bath, or fluoride is added to inhibit this attack, rough deposits will result. Plating for 15 to 20 min. in this copper strike bath will permit the copper pyrophosphate bath to be used without the addition of fluoride. Cyanide type baths do not

readily attack magnesium and can be used over thin copper strike coatings without modification.

Nickel can be applied from any of the conventional baths. It is preferred that the nickel bath have a pH of about 4.0 or above. A copper plate of about 0.0005 in. thickness, particularly on complicated parts, must first be applied to prevent attack of the magnesium through the pores in the copper plate.

Cadmium and Zinc have been applied directly over the zinc immersion coating from standard cyanide baths. An initial copper strike, or copper plating, produces better results than application directly over the zinc immersion coating.

Brass may be applied directly from a standard cyanide plating solution, or applied after copper striking.

Silver may be applied from conventional cyanide baths after applying a copper coating of about 0.0003 in. Plating silver directly over the zinc coating is only fairly successful.

Chromium has been applied directly to the zinc immersion coating in standard baths but the adhesion of the chromium deposit has not as yet been satisfactory when applied in this manner. Copper-nickel-chromium deposits may be satisfactorily applied.

In general, various combinations of electro-deposits are possible, but these usually depend upon the initial deposition of copper over the zinc immersion coating.

Racks

Copper, or copper-plated steel racks are preferred, but magnesium alloy racks may also be used. Organic rack coatings must be used to confine the exposed rack area to an absolute minimum for electrical contact with the magnesium part.

welded with a rod containing aluminium and zinc, however, cracking would occur in the weld metal although the cold strength of the weld metal had been increased by the use of a higher strength rod.

To check the observations made in production welding, a standard test was adopted in which the weld was subjected to considerable restraint. These tests confirmed that the calcium content of M and FS-1 alloys, especially the latter, was the greatest single factor in weld cracking.

Examination of the structure near the cracks indicated that the width of the solidification range, which influenced the amount of low melting constituent at the grain boundary, should control the weld cracking. Since FS-1 alloy, of lower alloy content than JS-1 alloy had shown the most weld cracking, samples of this alloy with calcium varying from less than 0.01 to 0.26% were heated to various temperatures, quenched in water and examined metallographically for low melting constituent. It was found that calcium, by lowering the solidus, increases the solidification range. Tests on M alloy showed a similar but less marked effect. The solidus, liquidus and width of the solidification range for the four alloys are shown in Table II.

Another factor which became evident in determining the tendency to weld cracking was the amount of shrinkage occurring during solidification and cooling of the weld metal. Table III shows shrinkage data, from

TABLE I.—MAGNESIUM SHEET ALLOYS IN ORDER OF INCREASING WELD CRACKING TENDENCY.

Downmetal Alloy	Composition, Balance Magnesium		
	Aluminium	Manganese	Zinc
M	—	1.5	—
JS-1	4.8	0.2	0.9
J-1	6.5	0.2	1.0
FS-1	3.0	0.3	1.0

TABLE II.—APPROXIMATE WIDTH OF SOLIDIFICATION RANGE OF THE MAGNESIUM SHEET ALLOYS.

Downmetal Alloy	Liquidus, F	Non-Equilibrium Solidus, F	Solidification Range, F
M 0-1% Ca	1290	1182	18
JS-1	1160	1050	110
J-1	1135	1000	135
FS-1 0-15% Ca	1170	980	190

TABLE III.—FREE CONTRACTION IN SAND MOLD OF BAR 48 IN. LONG, IN. PER IN.

Downmetal Alloy	Shrinkage In. per In.
M	0.0154
FS-1	0.0138
JS-1	0.1029
J-1	0.0117

Eliminating Cracking in Magnesium Arc Welds

By P. F. George, *The Dow Chemical Co.*

ALTHOUGH shielded arc welding of magnesium alloys has resulted in a reduction of weld cracking from that encountered in gas welding, cracking occurs occasionally in arc welds made under highly restrained conditions.

Table I gives the order of cracking tendency of four Downmetal alloys, M alloy showing the least tendency to

cracking and FS-1 the most. Apart from FS-1, the greater the aluminium and zinc contents, the greater the cracking tendency. It was also noted that with M and FS-1 alloys, the higher the calcium, which is added to improve formability and rollability, the greater the cracking tendency.

M alloy welded with M alloy rod sometimes cracked in the heat-affected zone but never in the weld metal. If

From *Materials and Methods*, April, 1948, 27, 4, pp. 68-71.

which it will be seen that the shrinkage is greater in M alloy and less in the higher aluminium—and zinc-containing alloys. Sauerwald had shown previously that the shrinkage of alloys is less than of the pure metal, due to a certain expansion in the later stages of solidification. Fortunately, the alloys with more aluminium and zinc have less shrinkage than M alloy, making the stresses less during the last stages of solidification at which time weld-cracking may occur.

Weld cracking in M alloy was found to be practically non-existent with a calcium content below 0.15% and as 0.08 to 0.15% is necessary for good forming and rolling properties this is quite satisfactory.

When M alloy sheet is welded with a rod containing aluminium and zinc, the weld metal contains the cracks because the sheet cools first, contracts rapidly and causes high stresses in the weld metal before it has cooled down to the solidus. The aluminium and zinc containing weld metal would then contain the network of molten low melting constituent which would be unable to sustain the stress. Cracking occurs in M alloy sheet, welded with M alloy rod, if the calcium content is above 0.15%.

It was not possible to keep the calcium content of FS-1 alloy low enough to prevent weld cracking in restrained conditions without losing its good forming qualities. To eliminate weld cracking it was necessary to use a rod of higher aluminium and zinc content such as J-1, O-1 (8.5% Al, 0.5% Zn and 0.2% Mn) or C (9% Al, 2% Zn and 0.1% Mn) alloy rods. These lower melting point rods remain molten while the FS-1 base metal becomes completely solidified so that no stresses are applied to the parent metal whilst the low melting constituent is present in the liquid form in the heat affected zone.

It might, therefore, be assumed that M alloy could be welded with a higher alloy rod, but when so welded cracks occur in the weld metal of a highly restrained weld because of the greater difference in solidification temperature and the greater shrinkage of the M alloy as explained above.

No corrective measures were found necessary for welding JS-1—J-1 sheet alloys using rods of sheet composition, as these alloys have a narrower solidification range than the FS-1 alloy with calcium, and also a lower shrinkage value.

a coating of brazing alloy on one or both sides. This is particularly suitable for furnace and dip brazing, especially in cases where pre-placement of the filler metal is difficult.

A number of brazing fluxes have been developed by the Aluminium Co. of America to meet a wide range of requirements in the way of brazing temperatures and chemical activity of the flux, whilst the Air Reduction Co. has developed a torch brazing flux designated "Elite."

Proper joint design is necessary, as with other brazing processes, in order to ensure complete penetration of the brazing alloy. With laps less than $\frac{1}{4}$ -in. long, clearances of 0.006-0.010 in. are usually satisfactory; for longer laps, clearances up to 0.025 in. can be used. For best mechanical properties, lock-seam, lap, fillet and tee joints are preferable to the butt or scarf types. Wherever possible parts should be self-jigging, and if jigs are necessary they should not be made of steel, as distortion would result because of the difference in thermal expansion. In using aluminium alloy jigs care must be taken that an alloy is selected which will not melt at the brazing temperature. Also, because of the high heat conductivity there should be little contact between the jig and assembly.

In brazing closed assemblies, adequate facilities must be provided for the escape of gases, otherwise an explosion may occur as a result of the ignition of the gas formed by the action of the flux on the metal. Since the flux residues will cause corrosion, the design of the assembly should be such as to allow complete cleaning of the joint.

The corrosion resistance (as indicated by salt spray and exposure tests) and the mechanical strength of a brazed joint are similar to those for a gas-welded joint in the same alloy.

In furnace brazing the chief requirement is that temperature control should be within $\pm 3^\circ\text{C}$., and the circulating-air type of furnace should be used to ensure uniformity of heating. Parts with a thickness of 0.008 to 0.50 in. can be furnace brazed. Below 0.008 in. the moisture in the flux attacks the metal, often causing perforation in thin sections. Assemblies are sometimes preheated to 2000°C . for 10-20 minutes to remove excess moisture. Two to six minutes at the melting temperature is sufficient time for the alloy to flow into the joint. Wide variations in thickness in an assembly should be avoided because of the unequal heating rates.

Brazing Aluminium Alloys

By H. R. Clauser

BRAZING has many advantages to offer over welding in the fabrication of aluminium products. The cost is generally lower than gas or arc welding; the joints have a neater finish; the method is applicable to sections too thin to be welded and is readily adaptable to production line methods.

Until the late '30's, brazing of aluminium alloys was not considered practicable, but considerable impetus was given to the study of the problem by war-time requirements. The two main difficulties in the way of successful brazing were the tenacious nature of the oxide film present on the surface of the metal, and the narrow temperature range between the melting points of the brazing alloy and the metal being brazed, this being of the order of 60°C . or less. The brazing of casting alloys is still in the development stage, due to their lower melting points and

the consequent unsuitability of the brazing alloys developed to date.

At present four standard wrought alloys can be brazed commercially. They are commercially pure aluminium (25), and aluminium-manganese (35), both of which are not heat-treated, and the aluminium-magnesium-silicon alloys (53S or R353 and 61S or R361), both heat-treated alloys. Since the brazing temperature is above the annealing temperature in all cases, the brazing operation results in softening. Parts made from the heat-treatable alloys can be re-heat-treated or in some cases quenched from the brazing operation to attain high strength.

The brazing alloys used are basically aluminium-silicon alloys, 5% silicon for the higher-melting-point alloys, and 10% silicon, 4% copper for the lower-melting-point alloys. These filler materials are available as wire, shims, rings, washers, etc. In addition to the above, a special aluminium brazing sheet has been developed with

From *Materials and Methods*, May 1948, 27, 5, pp. 78-82.

Austenitic Cast Irons

Corrosion-Resisting Castings

Range The effect of adding 6% and over of nickel to cast iron is for the structure of the castings to show progressively increasing amounts of the soft constituent austenite. With an addition of 20% nickel the castings become completely austenitic, relatively soft and easily machinable though part of the nickel required to give the full austenitic structure may be replaced, within limits, by copper or manganese. These austenitic cast irons produced by nickel or nickel and copper show outstanding characteristics not found in ordinary cast iron.

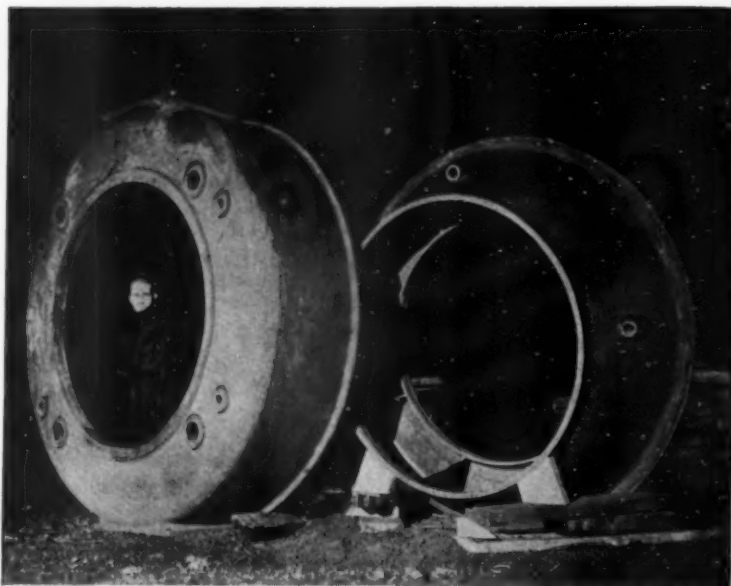
Properties The austenitic cast irons are tough and to some extent ductile. Their tensile strength is generally around 10 or 12 tons per sq. in. with a Brinell hardness usually in the range of 140-180. Higher hardness figures are obtainable but such alloys usually present machining difficulties owing to their tendency to work-harden. These irons have good resistance to erosion and abrasion, but perhaps their greatest value to engineers is their remarkably high resistance to corrosion.

Applications Corrosion-resisting cast irons are of great importance to chemical engineers and others faced with problems of corrosion, for they are well able to withstand the action of caustic alkalis of all strengths as well as weak mineral acids. Production of castings presents no undue difficulty and

the austenitic irons are in widespread and ever-increasing use for all types of equipment including containers, pipes, valves, pumps and other fittings which are in contact with a corrosive medium. Many applications may be found in the chemical field, in sewage disposal plants and in the automobile, petroleum, textile and paper industries. Moreover, a copper-free austenitic cast iron is obtainable and this is of particular value where copper contamination must be avoided as for example in many types of food processing.

Ni-Resist solves corrosion problem Ni-Resist, one of the best known corrosion-resisting cast irons, is

an austenitic iron containing from 14 to 16 per cent nickel, 7 to 8 per cent copper and from 1.5 to 3 per cent chromium, though modifications to the stated compositions are effected to meet specific requirements. Where necessary the copper may be eliminated if the nickel content is increased. Our illustration shows two Ni-Resist absorber tray castings each approximately 9 ft. 6 ins. in diameter, weighing $3\frac{1}{2}$ tons and cast by Sheepbridge Stokes Centrifugal Casting Co., Ltd. Ni-Resist was chosen for this application because of its superior resistance to the common corrosive reagents including acetone and acetic acid which are handled in these trays.



In contact with acetone and acetic acid, these Ni-Resist trays give long service under corrosive conditions.

By courtesy of Sheepbridge Stokes Centrifugal Casting Co., Ltd.

Write for a copy of our publication, "Ni-Resist in the Chemical and Allied Industries."

THE MOND NICKEL COMPANY LTD., GROSVENOR HOUSE, PARK LANE, LONDON, W.1

Similar thickness of material can be dealt with in dip-brazing, in which the assembly with brazing alloy in position is dipped into a bath of molten flux. Material as thin as 0.006 in. can be dip-brazed provided the bath is correctly dehydrated. Depending on the size of the assembly, dip-brazing can be completed in $\frac{1}{2}$ to 3 minutes. Although large thickness variations should be avoided, the process allows more latitude than furnace brazing. Contamination of the flux should be avoided and pure nickel pots are widely used, as also are certain ceramic linings. Racks are usually of nickel or aluminium. The parts may be attacked by the moisture contained in fresh flux unless the bath is dehydrated by dipping sheet aluminium

into it. Dip-brazing is not economical for intermittent working.

In torch-brazing the flame is not played on the filler metal, but on the base metal which melts the brazing alloy when the correct temperature is reached. The oxy-acetylene flame is the best for the process as it is hotter than oxy-hydrogen or oxy-natural gas and enables the brazing to be done more quickly with less distortion. Torch-brazing is applicable where there are large variations in thickness and where the assembly is unsuitable for the other processes. The minimum thickness which can be dealt with is 0.025-0.030 in., but there is no maximum, although sections heavier than $\frac{1}{2}$ in. are more easily welded.

Soft Alloys Used to Make Short-Run Sheet Metal Dies

By K. Rose

THE development of a metal forming die in tool steel can be a long and costly business, due to the difficulties involved in making the changes in the hardened die which experimental pressings show to be necessary.

From the Research Laboratories of the Ford Motor Co. comes the announcement of a new experimental die material. Sold under the trade name of Cerrobend, it is normally used for filling tubes to prevent distortion in bending. Its melting point is around 60° C. and at room temperatures it is softer than lead, but cooling to the temperature of liquid nitrogen develops a strength of about 11 tons sq. in.

To make a die of the low melting point alloy, the wooden pattern may be used to make a mould in plaster of Paris. The male half of the die may conveniently be made first. This is cast in the usual way, a procedure simplified by the low melting point of the alloy. Any minor repairs may be made with a soldering iron, using it carefully because of the ease with which the metal is fused.

A sheet of aluminium of the same thickness as the piece to be formed, and blanked out where necessary, is placed over the male half of the die,

and pressed against a rubber blanket to give it the die form. Die and aluminium piece are then walled off with plaster or modelling clay so that the cavity corresponds to the female die form. Locating pins to secure alignment may be inserted at this time. The female die is then cast, the aluminium piece serving to preserve the proper spacing between the die halves and also to prevent the molten metal fusing the male half.

The strength falls off rapidly with rise of temperature and the dies must be used immediately after chilling, asbestos gloves being necessary for handling. Sheets of asbestos above and below the dies in the press help to retard the rise in temperature.

An Olsen testing machine is frequently used in the Ford Laboratory for making test pressings thus enabling die pressures to be determined during experimental runs.

After six to ten pressings have been made the dies need chilling again. Warpage is said to be negligible and the chilling can be repeated indefinitely. Any corrections to the die form can be made with a pocket knife when the material warms to room temperature.

Small dies made from conventional die steels have taken six to eight weeks to produce, whilst with this method, sample parts can be produced in one to two days.

New High Alloy Hard-Facing Materials Adapted to Automatic Arc Welding

IN the past mechanised hard-facing by arc welding has been confined largely to the use of mild steel and low alloys which can be fabricated as solid wire in coil form. The Stoodly Company has now developed a tubular construction that makes possible the production of high alloy hard-facing materials for mechanised welding.

The new filler rods consist of flexible steel tubing containing the various alloying elements in granular form. The method of fabricating these hard-facing alloys also permits a wide variation in analysis to meet specific conditions involving simple abrasion, impact, corrosion or heat as well as any combination of these factors. Some applications indicate the use of submerged arc welding, while in other cases an open arc would be more desirable from an economical or control standpoint.

COMPOSITION AND CHARACTERISTICS OF THE NEW HARD-FACING ALLOYS

Alloy	Composition, %	Characteristics
101	Cr 28, Ni 8, W 1.5 Mn 0.6, Si 1.0, C 2.0	For submerged arc. Machinable with carbide tools. R _a 32-36
102	Cr 5, W 1.5, Mo 1.5, Mn 0.75, Si 1.00, C 0.29	For submerged arc; multiple pass application. R _a 50-52
105	Cr 3, Ni 1.50, Mo 0.50, V 0.30, Mn 1.25, Si 0.50, C 0.25	For submerged arc; multiple pass application. Machinable with carbide tools. R _a 46-48
120	Cr 6, Mn 2, Si 1.2, Mo 0.1, Zr 0.05, C 1.0	For submerged arc. R _a 52-54
121	Cr 15, Mn 2, Si 1, Zr 0.25, C 2.5	For open or submerged arc. R _a 54-56
122	Cr 8, Mn 2.5, Si 1.0, Zr 0.05, C 0.75	For submerged arc. Self-hardening. R _a 51-53
130	Tungsten Carbide 60, steel 40	For open arc. Ultimate abrasion resistance. Moh's scale, 9-10
Stoodly Manganese	Mn 14, Ni 4, C 0.70	For submerged arc. Full Hadfield manganese steel properties.

At present there are eight different hard-facing wires in coil form. Some are similar to present manual electrodes which have been in common use for years, while others have been developed for a specific wear problem. The accompanying table gives their composition and some of their characteristics.

From *Materials and Methods*, March, 1948, 27, 3, pp. 78-79.

From *Materials and Methods*, March, 1948, 27, 3, pp. 78-79.

One difficulty thus far encountered is the feed mechanism which up to now has been designed to handle solid welding wire. Since these wires are of tubular construction, the feed rolls should be grooved to fit exactly the wire being run through them so that the feed is positive without excessive pressure under all conditions.

The use of the fabricated wires in coil form has now become standard procedure in a half-dozen manufacturing plants. In others the alloys are undergoing extensive tests to determine their suitability for a wide range of hard-facing applications. Tool joints are now supplied by manufacturers

with automatically applied bands of hard-facing placed at a critical position to increase the joint life several times over. Blades hard-faced by the automatic process have been added to one concern's carrying scraper as a standard equipment. Hard-faced auger flights on a rock boring machine offer another example of a protected product. It is believed that the life of ore handling and loading equipment which receives severe service could be increased at relatively low cost through automatic hard-facing. Other examples include conveyor screws, large bearings, grader blades, and shear blades.

Proper Precautions Eliminate Cracking in Tool Steel Heat Treatment

By S. D. Smoke

THE cracking of tool steels during and after heat treatment can be responsible for the waste of much material and labour. The improved tool steels of to-day are more sensitive to treatment than their predecessors and it is therefore more essential than ever that proper precautions are taken during treatment.

In the first place, the material should be in the proper condition, i.e., completely spheroidised so as to reduce the possibility of cracks due to hardening strains.

In the heating operations, uneven heating, overheating and underheating are causes of cracking. Before placing in the preheating furnace, tools should be warmed in a low heat furnace or in front of a hot furnace. Depending on the steel and the hardening temperature, warming temperatures will vary from 200° to 400° C. and preheating temperatures from 650° to 850° C. Steels with a hardening temperature above 950° to 1000° C. should be thoroughly soaked, at 800° to 850° C. and then brought rapidly to the hardening temperature. Those with a lower hardening temperature should be soaked at 650° to 750° C. and then heated slowly and uniformly to the hardening temperature. Although instruments should be used to control and record the temperature, a visual check can be helpful in avoiding uneven heating. Cracks due to uneven heating have a circular appearance on the quenched tool.

Overheating causes a number of minute cracks, invisible to the naked

eye, on the corners of the tool, whilst apart from cracking, underheating results in poor physical properties.

Salt baths and lead baths reduce heating times materially but their use does not lessen the need for careful preheating and adequate soaking at the proper temperatures.

There should be no delay between the parts being removed from the hardening furnace and their quenching. Good circulation of the quenching bath is necessary to minimise the stresses set up between unequally cooled parts of the tool, as a result of which cracks may occur. It is essential to keep the bath clean, as dirt, scum or flakes of scale cause soft spots which may result in premature failure of the tool. Tools should be removed from the quenching bath at the proper temperature and the use of temperature-indicating crayons for this purpose is recommended. In no case should the tool be quenched outright but should be removed from the bath at a temperature between 100° and 200° C.

Careless tempering is the cause of a good deal of cracking in tool steels. Normally, tempering is considered as a means of obtaining the desired properties, but the part it plays in relieving quenching stresses should not be underestimated. Tools should be tempered immediately after quenching and for a sufficiently long time to remove the quenching stresses. Otherwise cracks may occur at any time, even after the tools are put into service. Where it is not possible to temper immediately, the tools should be kept at about 100° C. until the furnace is available. Even so, it is

desirable that tempering should not be delayed for more than an hour or two.

Where tools are to be re-forged, re-machined or re-ground, it is advisable to stress relieve before each of these operations.

The Influence of Small Contents of Lead on the Hot Workability of Austenitic Stainless Steels

By SIGGE BERGH

THE destructive influence of small contents of lead and tin on the hot workability of high nickel-chromium alloys of the nichrome type has recently been observed. In this paper information is given on the influence of small impurities of lead in austenitic steels, based on experience and investigations made by the author in the works of the Uddeholms AB during the last war. It is shown that to obtain good hot workability a threshold value of about 0.005% lead must not be exceeded. Liquid steel is able to dissolve some tenths of a percent of lead, but in the solid state the solubility of lead is very small and of the same magnitude as the threshold value mentioned. The author's investigations comprising spectrographical analyses, lead prints, etc., show that the presence of lead inclusions in the primary grain boundaries may be the explanation of the reduced hot workability of these steels, which are comparatively hard at rolling temperature.

From *Jernk. Annal.*, 1948, 132, pp 213-220.

REFRACTORY WARE

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From *Materials and Methods*, March, 1948, 27, 3, pp. 86-88.

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